# COMPARISON OF GROWTH AND NUTRIENT STATUS OF CITRUS LEAVES AND FRUIT

By

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# COMPARISON OF GROWTH AND NUTRIENT STATUS OF CITRUS LEAVES AND FRUIT

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Mineral nutrient content and morphological characters of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) were measured during a 15-month period representing a single complete growth cycle. Measurements were made at intervals ranging from 1 week during the time of new leaf development, bloom and early fruit growth to monthly during the latter part of the observation period for 6 cultivars of citrus ('Hamlin' orange, 'Pineapple' orange, 'Valencia' orange, 'Temple' orange, 'Murcott' mandarin and 'Marsh' grapefruit) and for a single cultivar ('Valencia' orange) growing under 6 varying rates of N and K fertilization. Comparisons were made to evaluate differences in mineral element content and morphological characteristics between cultivars and between levels of fertilization for a single cultivar.

Leaf growth of all cultivars followed an asymmetrical sigmoid pattern of growth, reaching maximum size and weight after 4 to 5 weeks of growth. Fruiting reduced size of FL in relation to NFL of 'Marsh' 'Hamlin' and 'Pineapple' but not of 'Temple' and 'Valencia'. High N fertilization promoted the development of larger and heavier leaves.

High K fertilization stimulated the growth of leaves of lower weight. Area of leaves was highly correlated with other leaf parameters indicating that measurement of a single leaf parameter might be used to estimate leaf area.

Fruit growth followed a sigmoid pattern for all cultivars. Fruit of 'Marsh' and 'Hamlin' were commercially mature at the beginning of stage III of fruit growth while fruit of the other cultivars went through an extended period of maturation in stage III.

The pattern of seasonal changes in mineral element content of the leaves and fruit was the same for all cultivars. Early fruit growth caused a decrease in the amount of N, P, K, Ca and Mg in the FL of all cultivars. Content of N, P and K were lower in FL than in NFL while Ca and Mg were higher in FL than in NFL for most cultivars.

Amounts of N, P, K, Ca and Mg in the leaves and differences between the amounts in NFL and FL were influenced by the level of N and K fertilization. Increased N and K fertilization caused high N and K in the leaves. N antagonized k at all levels of K fertilization but K depressed N uptake only at low levels of N fertilization.

# INTRODUCTION

There is a complex relationship between growth of the various meristematic areas of a fruit tree. Growth of roots, above-ground vegetative tissues and fruit is cyclic and there is competition between these meristematic areas for mineral nutrients, photosynthates and water. Numerous studies have been made regarding the effect of fertilization practices upon growth and yield of citrus trees and of the effect of fruiting upon vegetative growth responses. There has been a predominance of work on a few major citrus cultivars. Generally, the effects of fertilization and crop load have been evaluated using the morphological characteristics of the fully developed leaves and fruit. Further, most reports of changes in leaf and fruit characters have been made using dry weight measurements or calculation based on percent dry weight.

In view of the complex nature of these relationships it is not unexpected that many inconsistencies exist in observed responses of citrus trees to fertilization. This research was designed to measure, throughout the growing season, changes in morphological and mineral nutrient element characteristics of 3 major meristematic areas of the above-ground portions of different cultivars of citrus, namely fruit, leaves on non-fruiting stems, and leaves on fruiting stems. This information would then be analyzed to determine if differences in the growth patterns of leaves and fruit might be the reason for differences in cultivar response to fertilization and crop load. This type of data could also serve to define when major changes in tissues are taking place and when a change in nutrient status of the tree might affect these tissue changes most profoundly. Additionally, seasonal changes in these morphological and mineral element content characteristics might be influenced by nutrient element availability to the tree, particularly nitrogen and potassium.

Two distinct experiments were undertaken. The first was observation of morphological and mineral element content changes on a frequent time basis from the beginning of a new vegetative and reproductive growth cycle in the spring until fruit harvest for 6 citrus cultivars, 'Marsh' grapefruit, 'Murcott' mandarin, 'Temple' orange, 'Hamlin' orange, 'Pineapple' orange and 'Valencia' orange. The second experiment consisted of observation of the same morphological and mineral element content changes, over the same time period, of a single cultivar ('Valencia' orange) growing at different levels of nitrogen and potassium fertilization.

# LITERATURE REVIEW

## General Growth Habit of the Aerial Portion of Citrus Trees

### Vegetative Growth

Most important commercial citrus cultivars have a single trunk. The trunks are cylindrical, except in older trees where ridges may form on the trunk above large roots and below large branches. The top or crown of the tree is more or less spherical in shape. Orange or grapefruit have a dense canopy with numerous small branches, whereas the lemon produces a more open growth with fewer and larger branches. Except for some of the limes and the 'Satsuma' and Mediterranean mandarins, most citrus cultivars are upright in growth habit. This characteristic is easily seen in the branches where dominance of terminal growth is very marked (118).

The vigor of shoot growth as well as the pattern of shoot occurrence, varies greatly with cultivar, climatic conditions, age and health of a tree, and relative shoot position. Shoot growth, under California conditions, is most vigorous in the lemon, followed ordinarily by 'Valencia' orange, the navel oranges and the grapefruit (102). Growth of the citrus tree, like other tropical evergreens is cyclic and produces in distinct flushes (41, 96, 100, 115, 119, 135). The number of flushes and the amount produced in a particular period is dependent upon climatic and weather conditions, variety, and other factors. All commercial cultivars of citrus usually have 2 or 3 annual cycles of growth with 2nd and 3rd cycles primarily vegetative growth. However, under some conditions, summer and fall growth may be sparse or even absent (101). The number of cycles may increase up to 7 distinct flushes (96, 97, 115, 135). Seven flushes of leaves have been found on Florida lemon trees (94). Spring shoot growth may be divided into 5 morphological classes, ranging from flowering shoots with no leaves to all vegetative shoots (135). These are

A. Flowers but no leaves,

B. Flowers and few small leaves,

C. Several flowers and several large leaves,

D. Leaves and solitary terminal flowers,

E. Vegetative shoots - no flowers

New shoots arise by elongation of axillary buds, principally on 1-year wood. They occur in fairly substantial numbers on 2-year wood and to a limited extent on older shoots. The majority of new shoots appear in the axils of the leaves near the apex of the bearing shoot (135). The 2nd and 3rd flushes are less regular and less general than the spring flush. Flowering shoots are not numerous during the summer growth flush, but can occur, and occasionally may set fruit to form a second crop (135). Shoot growth is terminate in character with from 3 to 9 or more leaves expanding almost simultaneously. A leaf may live from 1 to 3 years and a tree typically carries from 3 to 4 overlapping cycles of leaf growth. A mature tree may have from 50,000 to 100,000 or more leaves (150). The total number of leaves on a 19-year-old grapefruit tree has been estimated to be 70,000 (10). The crown surface area of a tree is far smaller than the total leaf area, so that a considerable overlapping of leaves occurs. In older trees, crown surface areas are around 32% of total leaf area while in younger trees crown surface areas are about 51% of total leaf area, indicating a greater degree of leaf overlapping and shading of interior leaves in older trees (170).

## Flowering Pattern and Fruit Growth

A juvenile period exists as part of the life cycle of many plants, including citrus. During this period flowering of a plant is inhibited or prevented. In citrus, juvenile characters are very prominent and often persist for several years. They included thorniness, vigorous and upright habit of growth, slowness to fruit, and physical differences in fruit characters. The length of the juvenile period varies with different cultivars.

Continuity of fruiting from season to season is assured by the ability of the tree to initiate fruit buds on any of the vegetative cycles, once the juvenile period has been terminated. A small portion of new shoots develop inflorescences and a relatively high percentage of new shoots are vegetative. Nodes on the apical portion of a shoot produce most subsequent shoots, which results in most of the fruit being borne in proximity to the end of the branch. In general, new shoots are not numerous on old wood except in certain cases where 1-year bearing wood is lacking. There tends to be an alternation of vegetative and floral shoots. Fruiting shoots tend to make vegetative growth during subsequent growth cycles. Most flowering occurs on shoots which made only vegetative growth during prior growth cycles. Leafy inflorescences appear to be better able to set and retain fruit to maturity than leafless inflorescences (117, 135).

In subtropical climates the main bloom period of citrus is the spring. Various factors, such as diseases and rainfall or irrigation preceded by a dry period, may produce blooming of single branches, a whole tree or even an orchard at any time of the year. Fruit set on bloom of summer and fall growth flushes is usually inferior in quality. Cases have been noted of flower buds swelling in autumn, remaining quiescent through the winter, and blossoming in early spring. In hot, tropical climates near the equator, all citrus tend to bloom throughout the year, except as influenced by periods of drought (57).

A mature tree may produce 10,000 to 100,000 flowers each spring. Many flowers start to develop into fruits, but after a heavy shedding of small fruit during the bloom period, and a thinning drop of young fruit 2 or 3 months later, only a small percent develop into fruit that reach maturity (150). The primary cause of dropping of flowers and young fruit is a weakening of tissue in preformed abscission zones at the point of attachment of the base of the ovary to the disk or of the pedicel to the twig. The actual mechanism of the process is not well understood, but it is believed to be triggered by growth regulators in response to either external or internal changes.

The fruit of citrus is a type of berry called a hesperidium. It arises through growth and development of the ovary which consists of approximately 10 united carpels clustered around and joined to the floral axis (137). The pericarp or ovary wall is the portion of the fruit exterior to the locules. The exocarp or flavedo consists of the outermost tissue layer of the fruit. The endocarp is the portion of the locular membrane that sheathes the outer hemispherical side of the peeled and divided fruit segment. It is the inner layer of the pericarp or the adaxial face of the hypothetical carpellary leaf. From this tissue arise the specialized endocarp hairs called juice sacs which make up the edible portion of citrus fruits. The mesocarp or albedo occurs between the exocarp and endocarp.

The septa are fused walls of adjacent carpels. Facing each carpel is a locular membrane which is a layer of endocarp-like tissue with an epidermal layer on the face of the locule. Between the 2 locular membranes is a mesocarpous tissue. With some citrus fruit this intervening mesocarpous tissue is easily torn so that the fruit segments may be easily separated. The term segment is sometimes applied to the locular contents (the juice sacs and seeds) along with the locular membrane in which they are enclosed.

In the flower and fruit, the ovule and the seeds which develop from them are present in 2 rows along the margins of the carpel walls, i.e. where the margins of the carpels join to the axis (137).

The growth of citrus fruit follows a typical sigmoid growth pattern. Bain (8) and Hassaballa (77) divided the growth of 'Valencia' orange into 3 stages:

Stage I: Rapid cell division, lasts for several months after petal fall and is characterized by increases in thickness of the pericarp.

Stage II: Rapid growth in size, lasts about 6 months and is characterized by cell enlargement and cell differentiation of the pericarp.

Stage III: Fruit matures, the color changes, and the growth rate slows.

## Seasonal Changes in Size and Morphology of Citrus Tissues and Factors Influencing These Changes

### Leaf

Leaf surface has an important role in the nutritional economy of the plant. As early as 1897, Bedford and Pickering (12) tried to estimate the effect of various cultural treatments by measurement of apple leaves. They stated that "for annual measurement of vigor of the tree we have relied on size or weight of the leaves" and that "the size of the tree may be taken as a record of the past history... whereas the size of the leaf is a measure of the vigor of the tree at the time being". Since that time, a considerable number of papers on the relation of leaf surface to tree growth have been published (170).

Although photosynthesis may take place in stems, roots or reproductive organs, it is the leaves which are principal photosynthetic structures in the higher plant. Normally, leaf development is profoundly influenced by the environment up to maturity of the tissues, when further expansion becomes impossible. When the leaf tissue matures there is normally little morphological change, anatomical change usually being limited to changes in the thickness and composition of the cell walls, but biochemical and physiological changes continue. There may be changes in stomatal behavior, in photosynthetic rate, in the amount of stored materials the leaf and in the pattern of other biochemical activity (58).

Although the methods used by different workers have varied and their results are sometimes conflicting, the general trends of the earlier investigations show that estimation of leaf area furnishes a valuable, objective measure of growth status of fruit trees (170).

Bedford and Pickering (12) have shown that many kinds of "neglect" in cultural practices result in a decrease in size of the leaves, as well as a decrease in stem growth. As regards to leaf size, Millella and Deidda (106) observed that frequent irrigation intervals and higher nitrogen rates increased leaf length and width of 'Valencia' orange. However, Lenz (99) in a field experiment with 'Valencia' orange found that leaf size was more affected by amount of yield than by nitrogen fertilization. Mann (101) reported that deficiency in K caused considerable reduction of leaf size of deciduous fruit trees, while deficiency in Ca resulted in great increases in leaf area. Bedford and Pickering (12) found that the size of apple leaves was decreased for a year or 2 if the trees were not cut back at time of planting nor subsequently pruned. Austin (5) reported that trees which had been severely cut back, as well as thinned, had smaller leaves throughout the year than those which had been thinned only. Chandler (28) reported that leaves on twigs on pruned peach trees were larger than those on unpruned controls, though the total leaf surface was greater on the latter. Chandler and Heinicke (29) have shown that pruning tends to reduce leaf surface in the vine and apple. Many workers have found that blossoming and fruiting exert a great and varying effect on leaf development. Gourley (67) reported that the mean leaf area of an apple tree was smaller in the bearing than in the non-bearing year, and Gourley and Howlett (68) found that when a branch of an apple tree, ringed the previous season, bore a heavy crop of fruit, it tended to have smaller leaves than an unringed branch that was not bearing a crop. Other authors have concentrated upon the leaf characteristics of particular types of growth, such as bearing and non-bearing spurs. Harley (76) found that mean leaf area on non-bearing spurs was about double that of bearing spurs. Kraybill _et_ _al_. (95) have found similar relationships. Sauer (135) studied 5 different types of spring shoots of navel oranges and reported that the largest leaves were borne on vegetative shoots with no flowers and the smallest leaves were found on shoots which were predominantly floral. On the other hand, Randawa and coworkers (113, 114, 115) working on 'Valencia' and 'Hamlin' oranges and 'Marsh' grapefruit in India found that flowering shoots had greater mean area of leaf per shoot than non-flowering shoots. Admed and Musahibuddin (1) reported similar results under Indian conditions on sweet orange and grapefruit.

The effect of rootstock on leaf growth has been shown by Swarbrick and Nail (166). They reported that mean internode length on various stocks and leaf area per unit length of stem were directly related to the vigor of the stocks. For a particular stock there was a close correlation between the size of a leaf and the length of the internode below it. Smith _et_ _al_. (160) reported that leaves of 'Parson Brown' orange were slightly larger than leaves of 'Valencia' or 'Hamlin' but not different from 'Pineapple' orange.

Jones (84) worked extensively with many types of leaves and methods for measuring them. He found that many factors influence leaf shape of tea, although the effect of these factors was less than the effect found on leaves which have a more complex shape. Fordham (62) working with tea estimated leaf area by measuring leaf length and width. In citrus, Turrell (170) established a logarithmic correlation between area and leaf fresh weight.

Thus, cultural practices, bearing habit and rootstock exert an influence on the development of leaf area. Maintenance of good nutrient and moisture levels in the soil, and minimal pruning result in large total leaf area. Studies of the effects of fruiting on leaf area of bearing shoots have given contradictory results in different climatic areas of the world. (76, 95, 113, 114, 115, 135).

Fruit

The size of orange fruits varies considerably with different cultivars. Some of this size variation may be attributed to the genetic nature of the cultivar (84) and some to the rootstock. 'Valencia' oranges are generally smaller than are navel oranges. In Florida, Harding, Winston and Fisher (75) reported that the average weight per orange was less for 'Conners Seedling', 'Parson Brown', 'Pineapple', 'Hamlin', and 'Jaffa' oranges than for other cultivars investigated, including the 'Valencia'. 'Parson Brown' and 'Valencia' were larger on rough lemon stock than sour orange stock. Recently, Reese and Koo (121) reported that early maturing 'Hamlin' (Nov.-Dec.) produced significantly smaller fruit, whereas the later maturing 'Valencia' (Mar.-June) had the largest fruit. 'Pineapple', a midseason fruit (Jan.-Mar.), was intermediate in size. The problem of small fruit size is particularly acute with 'Hamlin' on sour orange. Bitters and Bachelor (15) and Bachelor (6) reported that the largest 'Valencia' fruit were obtained on trifoliate orange stock, and the smallest on sweet orange stock. Fruit size on 'Cleopatra' mandarin, rough lemon, grapefruit, and sour orange stocks were intermediate, in decreasing order. Only a partial (negative) correlation was found between size of fruit and number of fruit on a tree. Fruit size of 'Washington' navel oranges varied more due to seasonal variation in climatic conditions than did 'Valencia'. The largest 'Washington' navel orange fruit sizes were on sour orange, followed by the trifoliate orange, rough lemon, 'Cleopatra' mandarin, and grapefruit in decreasing order of size. In years when fruit sizes were large, there was less influence of the rootstock than in years when they were small.

Marloth (102) found that the fixed effect of rough lemon rootstock producing larger fruit could have been to some extent counter-balanced by the variable effect of trees with a larger crop producing smaller fruit since the crops borne by young trees on rough lemon were some 25% greater than those of trees of the same size on sweet orange.

Leaf number and leaf area affect the size of fruit. Shamel and coworkers (138, 139, 140, 141) investigated the relation of amount of foliage to fruit size and found that the size of fruit increased with increase in number of leaves. They concluded that 90 leaves per fruit were necessary to produce fruit of size 200 (2.94 in. or 7.47 cm in diameter) with 'Valencia' but only 60 leaves to produce fruit size of 176 (3.06 in. or 7.77 cm in diameter) with 'Washington' navel. Leaf area required to produce 1 kg of fruit changes with age of tree. Turrell (170) indicated that only 2.3 $m^2$ of leaf area are required to produce 1 kg of fruit on 9-year-old trees, while 4.3 $m^2$ were needed to produce the same amount of fruit on 4-year-old trees. Efficiency in fruit production increased rapidly until the trees were 9 years old, then declined slowly as the tree aged, 1 kg of fruit requiring 3.6 $m^2$ of leaf area on 35-year-old trees.

Working in internal decline of lemons, Bartholomew (11) found that the growth rate of individual lemons is influenced not only by soil and climatic conditions and the time of the year when fruit set but also by the location of the fruit on the tree. While the height on the tree and the location, whether within the foliage or exposed on the outside, appeared to have an influence, the most important factor seemed to be the condition of the branch on which the fruit was borne. He concluded that the variation was probably due to differences in the amounts of water and other substances carried by the different branches.

Light intensity influences the growth rate of citrus fruit. This has been shown by Waynick (174, 175) when he observed the growth rate of 'Valencia' fruits inside and outside of the tree. He found that the growth curves of inside and outside fruit had different slopes, and while outside fruit may have stopped developing, inside fruit continued to grow for a much longer period.

Deficiencies or excesses of mineral elements in the soil may affect fruit size. Low K and deficiencies of Mn, Zn, Fe, Cu, and Mg have a negative effect on fruit size. The size-reducing effect of K deficiency or the size-increasing effect of ample K has been noted in field trials by Benton and Stokes (13), Bahrt and Roy (7), Reuther and Smith (125), Parker and Jones (111), Chapman (32), Winnick (178), Deszyck and Koo (42), Deszyck, Koo, and Ting (43) and Chu (38). Generally, fruit from Mn, Zn, Fe or Cu deficient trees is smaller. An increase in tree N, within the range for high-level production, will have an adverse effect on fresh quality of grapefruit and oranges, and will reduce orange fruit size. In Florida, Reese and Koo (120, 121) reported that for 'Hamlin', 'Pineapple' and 'Valencia' oranges, increase in K rate increased fruit size, whereas increased N produced significantly smaller fruit. Reitz and Koo (123) found that the effect of N on fruit size of 'Valencia' orange was less than the effect of K. Different cultivars respond differently to fertilizer levels. Koo et al. (94) found that lemon fruit production increased with increased rate of N application. The optimum rate for 'Persian' lime is about 40-50% higher than the rates recommended for oranges and grapefruit (124). Reduction in yield of 'Pineapple' oranges was reported by Stewart (164) when ammonium nitrate rates higher than 224 kg/ha/yr were applied.

Deszyck et al. (43) reported that 'Hamlin' trees outgrew 'Valencia' and produced nearly twice as much fruit by volume when similar K rates were applied. N effects on fruit size of grapefruit have been inconsistent. Martin (103) showed that high N in winter was necessary for adequate production of Arizona grapefruit, but if the high-N program continued into the summer, the % of fancy fruit was markedly reduced. In Florida, grapefruit studies have shown that an increase in N supply results in smaller fruit (122, 146, 153). In solution culture of 'Washington' navel at either deficient or adequate P levels, increases in P level caused reductions in fruit size (33). In field experiments, the effect of P on orange fruit size have not been in complete accord with results from solution culture studies. Innes (83) and Bar-Akiva (9) have shown that where yields were increased with P, fruit sizes of grapefruit were also increased. Embleton et al. (48) showed no effect on lemon fruit size where yields were increased with P. Unrecognized trace-element deficiencies or excesses may have been involved. Salinity accumulations due to insufficient rain or irrigation may exert size-decreasing effects. In areas of high salt accumulation, the size of the fruit will tend to be subnormal, and lemon fruits thus affected tend to become tree ripe before normal picking time (31). Although S deficiency of citrus has been demonstrated on navel orange trees growing outdoors in soil cultures (33), no deficiency has been reported under field conditions. In solution culture, S-deficient trees produced fruits which were often somewhat undersized and misshapen, and they failed to develop the orange color characteristic of navel oranges grown in the area of Riverside, California (33).

Soil moisture influences the rate of change in size of fruit and the ultimate size of the fruit. These influences have been described for various cultivars of citrus such as 'Valencia' orange, navel orange, grapefruit, and lemon. Waynic (175, 176, 177) showed that the most important factor determining growth and final size of fruit of 'Valencia' was the water available in the root zone during the period of most rapid fruit growth. Fruit which had not reached average size by this time did not reach average size by picking time 7 months later. He found that with the exception of fruit initially very large, those which were smaller 4 months after bloom grew more rapidly than those larger, and they equalled the latter in size at picking time. He also reported that fruit from trees on the sandier soil types definitely reached full size earlier than did fruit from trees on heavier types. Halma (73) recommended a relatively favorable water balance in leaves of navel orange. Compton (40) indicated that navel orange fruits increase in circumference within an hour or 2 after addition of water. He reported that there are 3 factors which distinctly affect water deficit in citrus: high air temperature, lack of available soil moisture, and strong winds. Halma (72, 73) found for grapefruit that during the growing season, weekly growth increments of fruit tend to follow the same general direction as weekly soil moisture curves and that the "relative saturation deficit" in the leaves shows an inverse trend. The term "relative saturation deficit" (R.S.D.) designates the difference (in % of weight at saturation) between the weight of freshly picked leaves and that obtained after artificial saturation. Furr and Taylor (66) found that changes in apparent growth rate of lemon fruits serve as an excellent index of the relative water deficit of the trees. If trees suffered a deficit which caused leaf roll, there was a pronounced reduction in final size of fruit on all soils but if the deficit was only moderate to slight before water was applied, then the final size of fruit was small only on light and sandy soils. Jones and Embleton (85) reported that trees grown under conditions of restricted water produced small fruit.

Time required for maturity of fruit has been intensively examined by many researchers. Reed and Halma (118, 119) made attempts to study certain relationships between the flowers and fruits of lemon. He found that time required for fruit to reach maturity varied from 7 to 14 months depending upon environmental conditions. The season at which fruit was set appeared to influence the time which was required for maturity but was not the only factor. Bartholomew (11) indicated that the time of year when lemons set, the age of the tree and climatic and soil condition were all factors determining the growth rate of lemon fruits. Some fruits may mature in 7 or 8 months, while others growing on the same tree may require as much as 14 months to reach maturity.

## Seasonal Changes in Mineral Element Composition of Citrus Tissues and Factors Influencing Such Changes

### General

A major objective in nutritional work with citrus has been to develop criteria and methods for evaluating the nutritional status of the tree, thus providing more accurate guidance for fertilization practices. Investigators working with tree fruits as well as other crops have come to feel that the plant itself offers a more promising means of diagnosing nutrient status and fertilizer requirements than the soil. At the same time it is recognized that any overall evaluation of tree condition, fertilizer requirements, and recommended soil management practices will require considerable soil and management information in addition to that which is furnished by the plant (34). The concept of leaf analysis for fruit trees (98) is that leaf analysis may be regarded as an index of the nutritional status of the tree irrespective of the nutritional status of the soil. Leaf analysis of high performance trees is also a valuable approach, but must be supported by evidence showing that such standards have a fixed or unique value. As to specific work on citrus, much less has been published to date than on certain other plants such as apple. In the 1930's (10) suggestions were made that nutrient ratios in leaf ash composition of grapefruit could be used for assessing the nutrient status of the soil, and it was proposed that the composition of certain high-performance trees be used as standards. At that time no such standards were locally available for grapefruit, and the authors made use of published analysis of California citrus trees (34). Later, Oppenheimer (109) analyzed leaves of 'Shamouti' orange from various groves in Palestine, and obtained results considered useful in fertilizer recommendations in that country. Innes (83) working with grapefruit in Jamaica suggested that the critical values be reported as % of dry matter of the leaf. Concurrently, reports were made that inorganic mineral content of citrus leaves was related largely to the age of the leaves (70, 86, 157). Smith (150, 151) has summarized the periodic effect of leaf age on mineral nutrient content. First, there is a high state of flux in young leaves during expansion and shortly after when metabolic activity is great. During this period the various elements are either increasing or decreasing at rather rapid rates. Such a period usually lasts 2 to 3 months. Second, the leaves again go through a period of change during the fall and winter months as the tree prepares for a new burst of growth and senility of mature leaves begins. Third, there is an interval of a few months between these 2 periods of rapid change when relative stability of composition occurs. Leaves originating at various times of the year have somewhat similar trends with respect to age. It is obvious that the age of leaves has a critical bearing on the composition of citrus leaves and that this factor must be taken into consideration in interpreting results. Establishment of seasonal trends for each locality possibly would enable the extrapolation or interpretation of analytical data from a leaf of any size

The effect of fruiting on mineral composition has been thoroughly investigated. Data from Embleton _et al_. (52) show that leaves from non-fruiting stems and leaves from fruiting stems of the same age can differ in mineral composition. Findings similar to these were reported by Folscher and Bruwer (61), Harding _et al_. (74) for N, P, K, Ca and

Mg: Aiyappa et al. (2) for N, P, K, Ca, Mn and Cu; Otaga (108) for N, P, Ca, Mg and Mu; Bradford et al. (18) for Zn, Mn, Cu, Fe and B; Bouma (16, 17) for N and P; Oppenheimer (109) for N; Nadir (107) for K; McGeorge (105) for P, K and Ca; Chapman et al. (37) for Ca; Smith (150) for N, K, Ca and Mg; Fudge (65) for N and P. However, in some cases, no differences or opposite results to those found by Embleton et al. (52) were reported by Chapman and Brown (34) for K; McGeorge (105) for Mn, Fe, Zn; Fudge (64) for K and Mg; Nadir (107) for N, P and Ca; Aiyaja et al. (2) for Ca, Mg, Zn, Cu and Fe; Smith (150) for P, K and Mg. Koo and Sites (93) reported that leaves from fruiting stems are more variable in composition than leaves from non-fruiting stems.

Chapman and Brown (34) and Wallace, Mueller, and Squier (172) reported practically no difference in nutrient composition between large and small leaves. Steyn (165) found that large leaves were appreciably lower in K than small leaves; differences in N, P, Ca, Mg, Na, Fe and Mn, Zn and Cu concentration were of little or no practical consequence. An understanding of the numerous factors that may affect the concentration of a given element in the leaves, should improve sampling procedures, sample handling and interpretation of analytical results (2, 16, 17, 46, 47, 53, 54, 55, 150, 151, 152).

## Specific Elements

### Nitrogen

N is commonly the 4th most abundant element in plants, following C and the elements of water. Plants absorb most of their N in the form of nitrate-N or ammonium-N. In acid soils they absorb more ammonium ions. Each form behaves differently in the soil. In general, the nitrate ion leaches readily, and the ammonium ion is fixed according to the exchange capacity of the soil.

N is a constituent of amino acids, nucleotides and coenzymes. In citrus it occurs in organic combination although traces of unassimilated ammonia and nitrate-N sometimes may be found in certain tissues.

N has greater influence on growth and yield than any other nutrient element. Trees grown with limited supplies of N may appear nearly normal but are undersized (158, 159). Such trees are largely unfruitful or highly erratic in bearing habit. They bloom sparsely, flush irregularly, and produce very limited twig and leaf growth. The foliage lacks the dark green tone and luster.

There is less consistency in the effect of leaf age on the concentration of N than on concentration of other mineral elements. N is absorbed in appreciable amounts at all seasons of the year, although the rate of absorption is lowest during the months of January and February (133, 134). A rapid increase in absorption is shown beginning in March, reaching a peak in April and May, at which time the rate was approximately double that during January-February. N appears to be of particular importance to tree at bloom time. Within limits, the number of flowers formed is related to the level of N in the tree. Migration of N from leaves to flowers takes place during this period (24, 26, 157, 173). It is worthy to note that the increase in rate of N absorption, as was true of other ions also, did not begin until sometime after bloom. It has been shown that with 'Washington' navel on sweet orange rootstock, N content of leaves declines with age (86). Very young leaves are relatively rich in N, containing more of this element than any of the other measured constituents (157) and % N decreases in spring leaves (87). Following the early high N levels there were fluctuations in % N which were related to both the application of fertilizer and the growth activity of the trees. The absolute amount of N per leaf is shown to gradually reach a peak during the winter months and to show a rather sharp decrease concomitant with the flush and bloom in the spring. The importance of N supply within the tree prior to and during the period of blossoming, spring growth, and fruit setting has been thoroughly documented (22, 23, 24, 25, 26). These investigators and others (79, 103) working with grapefruit in Arizona, found a marked reduction in % N of old leaves at the time of spring blossom and the new growth cycle. N content of both top and root bark also undergoes a reduction at this time (26) and substantial quantities of N are removed from the tree with the abscissed blossoms and small fruit.

N content in the plant is influenced by absorption rate from the soil and absorption rate is largely determined by solution temperatures (35, 87, 88). There is an increase in N concentration during summer months, associated with higher temperatures but this is followed by a rapid decrease in the fall of the year. Similar results have been reported in Florida (133, 134). While absorption is much less in winter months when soil temperatures are lower, there is some N absorption at all times (31). Nitrogen fertilization affects the amount of N in the leaves and fruits of citrus trees. N rates up to approximately 250 lbs per acre have increased % dry weight N in citrus leaves (125, 144, 155, 159, 160, 161).

In general, fruit size is reduced by increasing N from a relatively low level to a relatively high level (124). In California the number of fruit harvested is generally increased and size of fruit decreased as N in leaves is increased from 2.3 to 3.0%. California standards are less applicable for oranges growing in the acid sands of Central Florida (21, 119, 146). N increases fruit size in grapefruit (89) and levels of N in grapefruit appear to be lower than those suggested for orange leaves. Limited evidence indicates that the diagnostic leaf range from 2.0 to 2.2% in 5- to 7-month old, spring-cycle leaves of grapefruit in California desert area is sufficient to maintain yield (49). About 2.5% N in 4- to 7-month-old spring cycle leaves maintained full yield potential and thrifty tree condition of grapefruit in Central Florida (149).

Potassium

K is the only monovalent cation essential for all higher plants and indeed, for all living things except for a few microorganisms in which Ru can substitute for it. The principal role of K is that of an activator of numerous enzymes. Evans and Sorger (59) have listed no less than 46 enzymes from animals, higher plants and microorganisms which require monovalent cations for maximum activity. K is the activating cation in the majority of cases. Other monovalent cations can often substitute, especially Ru and ammonium ions, but they are usually less effective than K. No doubt K is the normally functional monovalent cationic cofactor in the living plant. Na and Li are often inhibitory (56).

With exception of K and Mg, all mineral cations which act as physiological factors or cofactors of plant enzymes are microelements, and even Mg is usually present in plant tissue at only a fraction of the concentration of K.

Unlike Ca, K is highly mobile in the phloem. Its utilization is therefore efficient in the sense that it is readily redistributed from older leaves to young growing organs. As a result, symptoms of K deficiency usually appear in the older leaves. In the stages of K deficiency, soluble carbohydrates often accumulate.

Soluble N compounds, including amines, agmatines and putrescines, often accumulate, the latter probably being responsible for necrotic spots which often appear on K deficient leaves (39, 71, 143).

The accumulation of carbohydrates and soluble N compounds point to diminished protein synthesis in K deficiency. In keeping with this conclusion is the observation (169) that fully mature bean plants, _Phaseolus vulgaris_, were much less sensitive to K deficiency than were young, growing leaves.

Three indirect effects of K on photosynthesis have been proposed. The first effect is a depression of Mg uptake by excess K, thereby limiting chlorophyll synthesis (56). A second effect has been reported by Fujino of Nagasaki University. He proposed a mechanism whereby K is involved in the opening of stomates (65). He found that upon illumination, closed guard cells accumulated K and opened. Darkened, they lost K to the surrounding tissue and closed. The finding has been confirmed and extended by others (60, 81, 82, 136). The third role proposed for K and indirectly linking it with photosynthesis is that it promotes the translocation of photosynthate from leaves (56).

Probably because of partial base substitution, normal vegetative growth of citrus proceeds over a wide range of leaf K. Studies have shown (34) that there is no sharp dividing line between deficient and adequate amounts of K in the plant, and vegetative growth is not materially affected by K in the plant over the range from about 0.35%

to 2.0% in 4- to 7-month-old leaves. Large outdoor sand culture studies using 'Valencia' orange in Florida (158, 159, 162) have shown the same results with values of Leaf K ranging from about 0.4 to 2.4%. Over this range, total growth was not affected during a 4-year period but there was a visible difference in the character of growth in the low K trees. Low K trees had smaller but numerous leaves, finer branches and more compact appearance. The large number of leaves and branches about offset the larger leaves and coarser branches of the tree receiving the higher level of K.

The fruit may be affected throughout the range from K deficiency to K excess. This was first shown in solution cultures in which K in 4- to 7-month-old leaves ranged from 0.3 to over 2.0% (34). The fruit became larger and coarser as the level of K increased. Numerous workers have shown a direct relation between K supply and fruit size (4, 7, 13, 42, 43, 47, 83, 112, 125, 126, 127, 144, 145, 159, 160, 178, 179). In no case did K fertilization reduce the size of fruit or improve rind texture.

K has more effect on fruit quality than any other element. Except for small size, best fruit quality occurs in the presence of low levels of this element. There is a progressive lowering of most quality factors as the K level is increased from a deficient level to normal or high ranges. Luxury K retards degreening in much the same way as high N or high P. K often increases rind thickness, coarsens texture of the fruit and decreases the juiciness of the fruit (150, 151).

As with N and P, the maximum concentration of K occurs in young leaves. However, in sharp contrast to the precipitous drop in concentration of N and P when these elements are in low levels in the soil, K concentration starts a gradual decline that continues for many months and does not make a rapid recovery after soil levels are increased. In contrast to N and P, K does not tend to accumulate in the leaf during the dormant season, little net change is noted in association with the inception of later growth cycles, and no removal immediately before abscission is evident. During winter months K intake by young orange trees in sand culture nearly ceases (134). Absorption rates are greatest from March to November. Leaves on orchard trees may loose as much as 60% of their K content during the fall and show little or no restoration of this element during the winter (157), which also indicates that little of this element is absorbed during that period.

On acid, sandy soils, K fertilization will readily increase K in leaves within a few months (7, 42, 125, 150, 151, 155, 156), but it may require 2 or more seasons to reduce high or excess K to low levels by eliminating K fertilization (150, 151). With soil of high K fixing capacity or on highly calcareous soils, leaf K is not related to exchangeable soil K (90, 150, 151). The effect of varying amounts of K fertilizer on orange and grapefruit have been extensively studied (42, 43, 144, 145, 154, 155). Limited investigations on the effect of the source of potash have been made, but all concluded that no significant difference in yield or fruit quality resulted (7, 92, 120).

Formation of new leaves and flowers is not dependent on much, if indeed any, K from the old leaves on the tree. It seems likely that this demand is met by reserves in the woody tissues, since losses of K entering the leaves can be influenced rather quickly by fertilizer practice (134).

Phosphorus

P is essential for sugar-starch transformation in plants. In photosynthesis and respiration, compounds containing energy rich phosphate bonds are needed for energy transformations in these reactions. In cell division, compounds containing P, the nucleoproteins, are required for the formation of the nucleus. In sugar-starch transformations, the enzyme called invertase contains P.

Incorporated into adenosine triphosphate, P is part of the "energy currency" of all living cells of whatever species. P occurs in phospholipids including those of membranes, in sugar P, various nucleotides and coenzymes.

The key role which phosphate plays in the energetics of metabolism and biosynthetic reactions suggests that its deficiency would be scarcely less disastrous than a deficiency of N. P is required for the synthesis of adenosine triphosphate and numerous other phosphorylated compounds. Its deficiency, therefore, causes immediate and reverse disruption of metabolism and development.

Citrus has a fairly low requirement of P. A ton of fruit contains about one-half pound or less and cropping removes from 5 to 10 pounds of P per acre per year. Healthy citrus leaves are capable of tolerating wide variations in P content. Foliar content of 0.1 to 0.6% P (dry weight basis) have been found. Rarely are values greater than 0.2% found in field-grown trees adequately supplied with P. The lower limit of adequate P in leaves appears to be about 0.08% of dry matter (36, 63, 69). Few responses have been shown to P applications, but 2 have been reported in California (3, 51). P absorption of young orange trees in sand culture is greatly reduced during winter months even though the trees were absorbing considerable N at that time (135). Detectable quantities of P have been found to move out of the leaves in conjunction with the occurrence of spring growth and bloom (157).

The P content is high in young leaves and generally decreases with increase in the age of the leaves (86, 87). It has been reported that in field plots where P is apparently adequate in the tree, P content is high in the young spring leaves and gradually decreases with increasing age of the leaves.

Chapman and Rayner (36) published the result of a 9-year experiment with orange trees growing outdoors in aerated solution cultures in which deficient and adequate levels of P concentration were maintained. They found that P content of the spring cycle leaves increased gradually during the growing season, generally reaching a peak in the period from September to January. The P content then decreased.

A difference in P content in leaves obtained from field experiments and from experiments with solution cultures has been reported (36, 86, 87, 157). In the field under conditions of deficient and adequate P, 1-month-old spring leaves are higher in P content than older leaves of the same growth cycle, whereas, in solution culture, under conditions of deficient and adequate P, 1-month-old spring leaves are lower in P content than 2- to 10-month-old leaves of the same growth cycle. Although the significance of this difference in the young leaves is not yet apparent, it does not alter the value of leaf analysis as a diagnostic tool for P deficiency, as young leaves are seldom used for this purpose.

Tracer studies have shown (14) that P is continuously circulating up and down the plant. P apparently does not move laterally in the plant (130), thus, asymetrical distribution results when only part of the root system is supplied with P.

Calcium

Ca is necessary for the formation of Ca-pectate which together with Mg-pectate binds the cellulose chains together in cell wall formation. Ca has therefore an important bearing on mechanical strength of tissues and in healthy, rapidly-growing plants, large quantities of Ca are necessary for the meristems of the roots, the stems, and the cambia.

In many plants, Ca neutralizes or precipitates certain organic acids which accrue from the metabolic activities of the plant. Oxalic acid, for instance, is precipitated by Ca thereby preventing a buildup of soluble oxalate ion. Ca acts as an antidoting agent against toxicity of other base elements such as Na, K and Mg. It has some effects on the permeability of tissues and the translocation of carbohydrates. Ca seems to be particularly important in root growth and functions. Collapse of the root system is usually the first symptom of Ca starvation. Following root damage from a deficiency of Ca, the top of plants can show a wide variety of non-specific symptoms such as Fe chlorosis, Mn chlorosis, salt toxicity, and general loss of vigor.

Ca also appears to be necessary for the absorption of nitrate N, since investigators have shown that Ca-deficient plants accumulate sugars and starches in the tissues and are unable to absorb nitrate N. Immediately after Ca-starved plants are supplied with this element, nitrate, if available, is found within the tissues in a relatively short time (56).

The citrus tree contains more Ca than any other mineral element. There is 4 to 12 times as much soluble Ca as K in the sap of mature orange leaves (70). Ca is virtually non-mobile in the plant and one tissue can suffer from lack of Ca while another has ample supplies of this element. No net loss of Ca takes throughout the life of the leaf (78, 157).

A wide latitude is permissible in leaf Ca without much effect on growth of the tree. One to 2% of Ca in 4- to 5-month-old leaves is sufficient in healthy, rapid-growing small seedlings. However, 0.8 to 1.23% of Ca content in 6-month-old leaves from non-fruiting terminals was reported as deficiency (163).

Ca effect on yield and fruit quality is difficult to study critically because of reciprocation of other bases. However, yields from orchards on calcareous or high Ca soils frequently seem to be less than on acid soils and 5-year-old trees in sand culture show sparse flowering and production when lime was mixed in the substrate (149).

The effect of soil levels of Ca upon Ca content of leaves has been difficult to determine due to the interaction of Ca and pH changes in studies previously conducted (148). A good degree of correlation has been shown between Ca intake and transpiration (134). Ca tends to increase in the citrus trees throughout their entire lives, and accumulation is more pronounced in Florida during the summer months, which is the period of greatest rate of transpiration (131). Ca content of leaves increases slowly to a maximum concentration and remains essentially constant thereafter. Ca is the predominant mineral element in the mature citrus leaf and appears never to be withdrawn (157). Others have shown that Ca in leaves increases rapidly until mid-winter and then Ca tends to decrease slightly. Together, they found that N, P, and K contents tend to decrease with increase in age of the leaves, whereas Ca, Mg contents increase (86, 87).

### Magnesium

Mg has at least 2 important roles. It is a constituent of both chlorophyll and activator of numerous enzymes affecting phosphate transfer, Mg is an element whose deficiency soon affects every facet of the metabolism of the plant. Chlorosis is an early symptom, followed by diminished photosynthesis. Biosynthetic pathways are deranged, as the result of inhibition of essential enzymatic transphosphorylations, and soluble nitrogenous compounds are present at elevated concentrations. In citrus, as in most other plants, this develops in older leaves. Under rather severe deficiency conditions, the leaves appear normal for the first several months. In the fall months, as some Mg is translocated from the leaves to the developing fruit, a bronze-colored yellowing called "bronzing" is developed (64).

Increasing Mg concentration in the soil solution causes increases in Mg in the leaves (168). Some absorption of Mg may occur at any period of the year if a tree deficit for this element exists, although during the summer it is certainly much more readily absorbed (134).

### Multi-element considerations

The absorption, assimilation and amount of an individual element found in citrus leaves is strongly influenced by the other mineral elements essential to tree growth.

Increasing the rate of N application has been found to affect leaf levels of most other micro and macro-elements in the leaves (150).

Further, Ca and K have shown antagonistic or reciprocative effects in respect to N. N has a strong antagonistic effect on P.

P absorption is reported to be antagonistic to the absorption of K, Mg and Cu, and synergistic to Ca, Zn and Mn in Florida (150). P is considered a weak antagonizer of N. In California, the research reports on P have generally agreed with those in Florida, except for the effects on N and Mg (30).

A more recent tabulation (51) summarizes combined experimental results of multi-element effects in P nutrition. Deficiencies of N, P, Ca, Mg and Zn are known to cause substantial accumulation of K in leaves. In determining K status and the need for K fertilizer, leaf analyses for these elements, as well as for K, need to be made so that the nutritional balance and status can be correctly evaluated. When there is much "luxury consumption" of K, due to high concentration in the nutritional medium, the absorption, and, more likely, the translocation of other cations may be depressed (56). In leaves with extremely high K, Mg level may be low and vice versa (19, 55, 142). High accumulation of K may bring on or aggravate Mg deficiency (44). In citrus, the strongest antagonism seems to be between K and Ca. It appears impossible to have high levels of both K and Ca simultaneously in citrus leaves (149).

Increasing the Mg concentration in the nutrient solution gave a very slight reduction in leaf K and practically no lowering of leaf Ca (162). For unknown reasons, Mg has a synergistic effect in Zn and Mn (27). Roy and Gardner (134) found that the intake of Mg was very low during the period November through February, increasing rapidly through the spring to a peak in late May and early June, and then decreasing to November. They also reported evidence of a return to the sand of slight amounts of this element. Smith and Reuther (157) showed the same pattern of absorption of Mg. Mg was found to build up to a maximum and then slowly decrease for the remainder of the leaf's life.

Ca, if separated from its effect on pH, appears to have very little effect on other elements. Under acid soil conditions, substantial increases in supplied Ca affected neither leaf Ca nor leaf N (152). When compared, leaf Ca was markedly increased and leaf N drastically reduced on the calcareous substate (149). This concurs with survey information that indicates a general lower N status under conditions of high leaf Ca (124). Boron causes a 25 to 30% reduction in leaf K and a compensatory increase in Ca and Mg (147).

# MATERIALS AND METHODS

## Plant Materials

Trees in all experiments were from established plantings at the Davenport grove of the Agricultural Research and Education Center in Lake Alfred, Florida. Experimental groves at the site were managed using typical cultural practices of the surrounding commercial plantings. Soil is classified as Astatula find sand, organic matter content 0.9%, cation exchange capacity of 2 meq per 100 g and pH 5.3 of the native soil determined as 1:1 soil:water suspension.

### Cultivar Experiment

Trees in this experiment consisted of 4 trees each of 'Pineapple' orange (*Citrus sinensis* (L.) Osb.), 'Hamlin' orange (*C. sinensis* (L.) Osb.), 'Valencia' orange (*C. sinensis* (L.) Osb.) and 'Marsh' grapefruit (*C. paradisi* Macf.) on rough lemon (*C. jambhiri* Lush.) rootstock and 'Murcott' mandarin (*C. reticulata* Blanco) and 'Temple' orange (*C. temple* hort. ex Y. Tanaka) on 'Cleopatra' mandarin (*C. reshni* hort. ex Tanaka) rootstock. The trees were growing in established fertilizer, irrigation, rootstock and yield trials. Planting distance was 7.62 m X 7.62 m for all cultivars except 'Temple' and 'Murcott' which were planted 6.3 m X 7.5 m. All sweet orange trees were planted in Spring 1960, and the 'Marsh' grapefruit in Spring 1961. 'Murcott' mandarin and 'Temple' orange trees were planted in Spring 1962.

Fertilization of the cultivars was variable. The sweet orange cultivars had been maintained from 1961 to 1968 on a 8-2-8-2 ($N-P_2O_5-K_2O-MgO$) mixed analysis fertilizer with beginning rates of N and K of 25 kg/ha/yr applied in 5 applications and ending rates of 56 kg ha yr applied in 3 applications. Beginning in 1968, these trees received 56 kg/ha/yr of N and 46 kg/ha/yr of K. In 1970, N rate was increased to 67 kg/ha/yr and K to 56 kg/ha/yr. These amounts were applied in 3 applications in Feb-March, June-July and Oct-Nov. These rates were attained by applying 8-8-8-8 base mix by mechanical spreader and supplementing the base mix with additional N to secure the desired N rate.

Trees of 'Marsh' grapefruit, 'Murcott' mandarin and 'Temple' orange were in buffer rows of other experiments and received fertilization equal to commercial production recommendations (124).

### Differential N and K Fertilization Experiment

Trees in this experiment were 'Valencia' orange scion on rough lemon rootstock. All trees were from an existing experiment designed to establish optimum levels of N and K fertilization. Planting distance was 7.62 m X 7.62 m. From the time of planting until 1968, the young trees were maintained on an 8-8-8-2 mixed analysis with beginning rates of N and K of 25 kg/ha/yr applied in 5 applications and ending rates of 56 kg/ha/yr applied in 3 applications. Fertilizer treatments were separated on all sides by buffer trees. In 1968, treatments were imposed which consisted of 4 rates of N and K in all combinations. The lowest N and K rates were commercial rates described in the cultivar study and the trees sampled from these plots were the same as the 'Valencia' trees used in the cultivar study.

Initial rates of N were 56 (rate N1), 112 (rate N2), 168 (rate N3) and 224 (rate N4) kg/ha/yr while K rates were 46 (rate K1), 93 (rate K2), 139 (rate K3) and 186 (rate K4) kg/ha/yr applied in 3 equal applications in April, July and October. In April 1970, N rates were increased to 67 (N1), 134 (N2), 202 (N3) and 269 (N4) kg/ha/yr and K rates to 56 (K1), 112 (K2), 167 (K3) and 223 (K4) kg/ha/yr. Ammonium nitrate and sodium nitrate were alternated as the N source. Sulfate and chloride of potash were alternated as the K source. The lowest rates of N and K were applied as 8-8-8-8 base mix by mechanical spreader. The higher N and K were applied as supplements by plots.

## Sample Collection

### Cultivar Experiment

Samples of leaves from spring shoots without fruit (NFL), leaves from spring shoots bearing fruit (FL) and fruit were collected periodically from each tree in the experiment. Non-fruiting spring shoots were marked by spray-painting a single leaf on such shoots in order to assure that leaves would be collected only from shoots which were non-flowering and non-fruiting throughout the entire sampling period. Samples consisted of 10 leaves per tree from non-fruiting shoots, 10 leaves per tree from fruiting shoots and 5 fruits per tree at each sampling date, except for 'Murcott' mandarin and 'Temple' orange where 20 leaves were collected per leaf sample due to the smaller leaf size. All samples were collected randomly from the entire tree. Leaf sampling was performed at 1-week intervals from March 14, 1973, until April 26, 1973, then at 2-week intervals until May 10, 1973, then monthly until September and then bimonthly until May 1974. Fruit samples were collected monthly from June 14, 1973, until harvest.

### Differential N and K Fertilization Experiment

Leaf and fruit samples for this experiment were made in the same manner as described for the cultivar experiment and on the same sampling dates, except that samples were taken on monthly intervals from May 10, 1973, until fruit harvest in May 1974.

## Sample Preparation and Analysis

Each sample of leaves and fruits was sealed into preweighed plastic bags and stored over ice in an ice chest until arrival in the laboratory. Samples from both experiments were then submitted to identical physical and chemical measurements.

### Physical Measurements

Weight. Fresh weight of all samples was determined immediately upon arrival in the laboratory. The leaf and fruit samples of the 4 trees in each cultivar or differentially fertilized plot were combined into a single composited sample and total fresh weight of each composite sample was determined. Total fresh weight of each composite sample was then divided by the number of leaves or fruit in the sample to secure a mean fresh weight per leaf or per fruit (FW).

The composited leaf samples were oven-dried at 70°C for 48 hours after which a dry weight measurement was made. This total dry weight was divided by the number of leaves in the sample to secure a mean dry weight per leaf (DW).

Fruit of the composited fruit samples were cut into segments, macerated in a food chopper, oven-dried for 1 week at 60°C and a total dry weight determined. The total dry weight was divided by the number of fruit to secure a mean dry weight per fruit (DW).

Leaf size. After weighing but before oven-drying the composite leaf samples, 30 leaves were randomly selected from the sample and the length and width of each leaf was determined. A mean length (LH) per leaf and mean width (WD) per leaf was then calculated. The LH/WD ratio was also determined.

Leaf area. Each of the individual leaves used for determining LH and WD were placed in a photo-electric planimeter and leaf area was measured. Mean leaf area (AR) was calculated.

Fruit diameter and length. Before sectioning and maceration, the diameter and length of each of the 20 fruits in the composited sample were measured. A mean fruit diameter (D) and length (L) were calculated. D/L ratio was also calculated.

Fruit volume and density. Total volume of the 20 fruits in each composite sample was determined using a water displacement procedure. Water was placed in a large graduated cylinder, the fruit placed in the water in the graduated cylinder and total fruit volume calculated as the difference in total water volume before and after addition of fruit. Total fruit volume was divided by the number of fruits to secure mean fruit volume (V).

Mean fruit density (DN) was calculated by dividing V by DW for each cultivar or fertilization treatment.

### Chemical Measurements

Analyses for N, P, K, Ca and Mg were made on all leaf and fruit samples using standardized methods of plant tissue analysis of the AREC laboratory in Lake Alfred. N was determined by the semi-micro Kjeldahl procedure (167), P by the vanadate method (91), K by flame emission spectrophotometry, Ca and Mg by absorption on a Perkin-Elmer atomic absorption spectrophotometer Model 503.

Initial data from the N, P, K, Ca and Mg determinations was measured at % of the mineral element per unit dry weight. The absolute amount of each element per leaf was then secured mathematically by calculating the total absolute amount of the element in the composited sample and dividing by the number of leaves or fruit in the sample.

## Statistical Analyses

Statistical analysis was done using various Statistical Analysis System (SAS) programs. Where desired, analysis of variance, regression, Duncan test and data plotting procedures were used.

# RESULTS AND DISCUSSION

## Seasonal Changes in Physical Characteristics of Fruit and Leaves of Six Citrus Cultivars

### Leaf Growth

Fresh weight (FW) and dry weight (DW) of leaves from non-fruiting stems (NFL) and leaves from fruiting stems (FL) of the 6 citrus cultivars are shown in Figs. 1 and 2. Growth of leaves using either type of data followed an asymetrical sigmoid growth curve as previously reported (84) for growth of leaves of herbaceous plants. Few reports of the growth of individual citrus leaves have been made. The data in Fig. 2 follows essentially the same pattern of Smith and Reuther (157) who reported on dry weight of 'Valencia' orange in Florida.

Max FW and DW of the leaves of all cultivars was reached in a very short time after the initiation of the spring growth flush (Figs. 3 and 4). These maximum were achieved around May 1 and there were only slight changes after this time. The time of reaching maximum weight was approximately the same for all cultivars. Although FL began growing at the same rate, they stopped growing before NFL. Thus, the differences in size between NFL and FL are due to the fact that FL grew to a smaller total weight during the first 4 weeks of leaf growth.

Data for NFL and FL are shown in Table 1. NFL were larger than

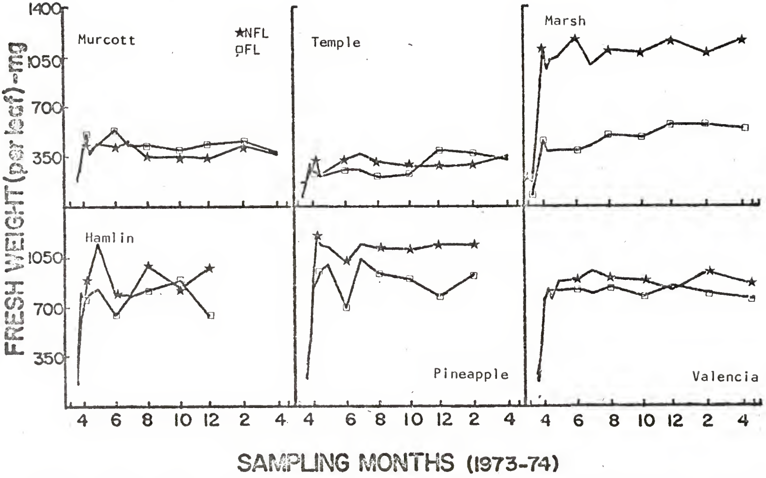

Fig. 1. Fresh weight of leaves from non-fruiting stems (NFL) and fruiting stems (FL) of 6 citrus cultivars.

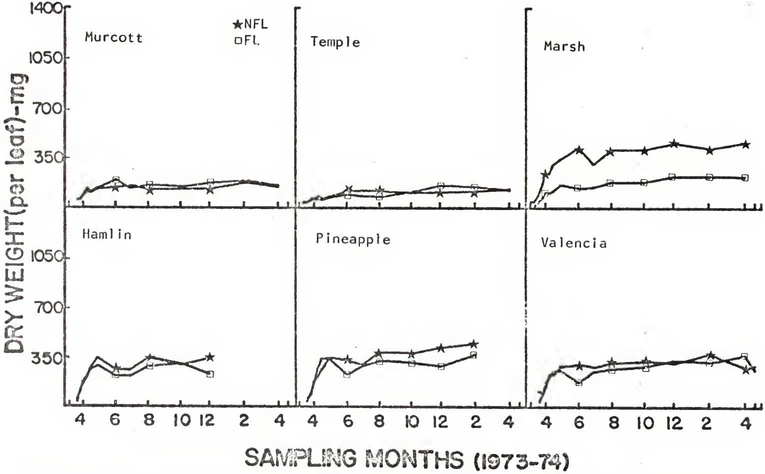

Fig. 2. Dry weight of leaves from non-fruiting stems (NFL) and fruiting stems (FL) of 6 citrus cultivars.

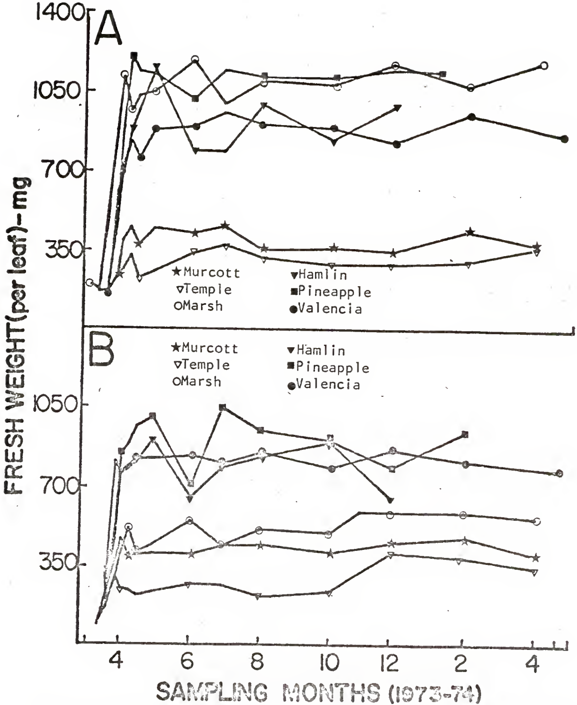

Fig. 3A. Comparisons of fresh weight of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

Fig. 3B. Comparisons of fresh weight of leaves from fruiting stems (FL) of 6 citrus cultivars.

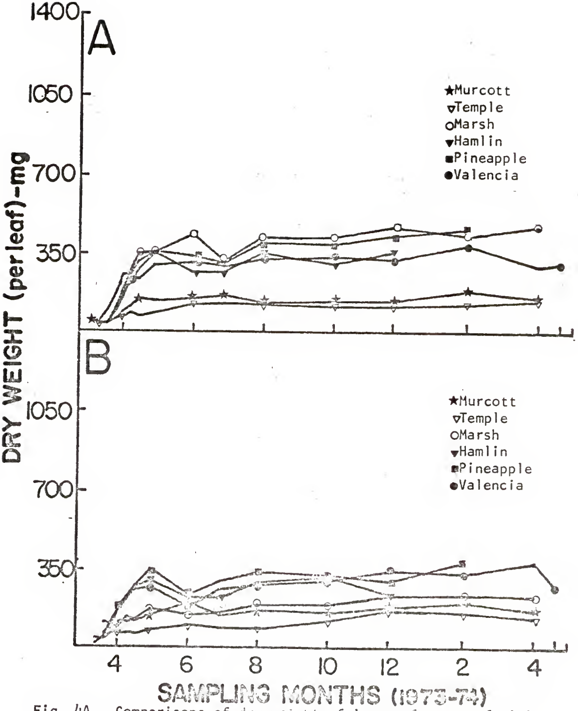

Fig. 4A. Comparisons of dry weight of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

4B. Comparisons of dry weight of leaves from fruiting stems (FL) of 6 citrus cultivars.

FL for 'Marsh', 'Hamlin' and 'Pineapple'. Difference in FW and DW of NFL and FL of 'Temple', 'Valencia' and 'Murcott' were very small and apparently not significant. Leaves of 'Pineapple' had the largest weight followed by 'Marsh', 'Hamlin', 'Valencia', 'Murcott' and 'Temple'. This was true for both NFL and FL, except for the 'Marsh' in which the FL are very small compared to NFL and of the same size as FL of 'Murcott'. The relative size of leaves of these cultivars, as shown in this data, does not agree with widely held opinion regarding leaf size of citrus cultivars, especially the relatively small size of the 'Marsh' grapefruit leaves. These data are for first flush leaves which were developed in competition with young fruit growth. In visual comparisons of citrus cultivars in the summer, second flush leaves are more obvious and are larger than first flush leaves particularly in the case of grapefruit.

Increase in width (WD), length (LH) and area (AR) of the leaves followed the same general pattern as those for FW and DW. These increases are shown for 'Temple' orange and 'Valencia' orange in Fig. 5 and Fig. 10. Comparative data for all cultivars is shown in Table 1. WD, LH, and AR of NFL of 'Marsh', 'Hamlin' and 'Pineapple' were larger than FL. NFL of 'Marsh' leaves were the largest in AR followed by 'Pineapple', 'Hamlin', 'Valencia', 'Murcott', and 'Temple'. Although NFL of 'Marsh' had the highest AR, they did not have the highest LH and WD, this was due to the fact that grapefruit leaves were oblaceolate (lance-shaped, with the broad end at the top) to obovate (having the shape of the longitudinal section of an egg, with broad end at the top) and sweet orange leaves were rounded at the base but pointed at the apex. NFL of 'Murcott' had larger AR than those of

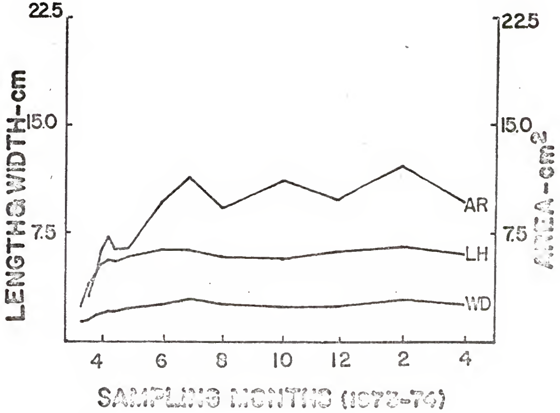

Fig. 5. Length (LH), width (WD) and area (AR) of leaves of 'Temple' orange.

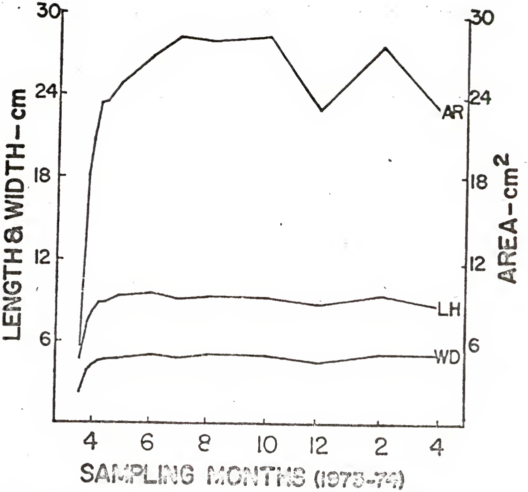

Fig. 10. Length (LH), width (WD) and area (AR) of leaves of 'Valencia' orange.

Table 1. Fresh weight (FW), dry weight (DW), length (LH), width (WD), and area (AR) of leaves from non-fruiting stems (NFL) and fruiting-stems (FL) of 6 citrus cultivars.

| Cultivar | Leaf type | FW (mg) | DW (mg) | LH (cm) | WD (cm) | AR ($cm^2$) |
|---|---|---|---|---|---|---|
| Murcott | NFL | 384.0 | 125.0 | 5.09 | 2.82 | 10.68 |
| | FL | 407.0 | 134.0 | 5.62 | 2.64 | 9.63 |
| Temple | NFL | 267.0 | 88.0 | 5.43 | 2.27 | 8.18 |
| | FL | 250.0 | 84.0 | 4.46 | 2.12 | 6.63 |
| Marsh | NFL | 905.0 | 293.0 | 7.65 | 4.22 | 24.91 |
| | FL | 414.0 | 137.0 | 5.11 | 2.64 | 10.31 |
| Hamlin | NFL | 798.0 | 241.0 | 7.83 | 4.06 | 21.46 |
| | FL | 660.0 | 213.0 | 7.16 | 3.82 | 18.48 |
| Pineapple | NFL | 972.0 | 294.0 | 7.98 | 4.42 | 23.88 |
| | FL | 748.0 | 249.0 | 7.28 | 3.91 | 19.32 |
| Valencia | NFL | 773.0 | 251.0 | 7.59 | 4.04 | 20.51 |
| | FL | 720.0 | 240.0 | 7.04 | 3.69 | 21.67 |

'Temple' although 'Murcott' leaves were shorter than 'Temple' leaves because 'Temple' leaves were narrowly lanceolate and 'Murcott' leaves were broady lanceolate. The increase in LH and WD of leaves did not occur at the same rate. This is apparent from the data in Table 2. The LH/WD ratio decreased during the first 4 to 5 months of the season indicating that LH increased more rapidly during the early part of the growing season while WD increased later during this time period.

AR of NFL was highly correlated with several of the other leaf measurements. Regression equation and correlation coefficients are shown in Table 3. Attempts were made to determine if these relationships were linear, exponential or quadratic. There were high degrees of correlation between AR and FW, DW, LH and WD for all cultivars. This was true whether the correlation was assumed to be linear, exponential or quadratic. These results are in partial agreement with results on 'Valencia' orange reported by Turrell (170). Turrell found a linear relationship between leaf fresh weight and leaf area. The data reported here and the regression equations shown in Table 3 are the first reports for the 5 other cultivars and the first determinations of these relationships under Florida conditions. These equations provide a means whereby leaf area can be determined from any of several other leaf measurements. Such estimates of leaf area can then be used to calculate total canopy leaf surface as described by other workers such as Turrell (170). However, the fact that mathematical relationships relating leaf measurement to leaf area in Florida do not agree with those derived in California would indicate that additional studies should be made in Florida to clarify these

Table 2. Ratio of leaf length (LH) and width (WD) for 6 citrus cultivars.

| DATES | MURCOTT | TEMPLE | MARSH | HAMLIN | PINEAPPLE | VALENCIA |
|---|---|---|---|---|---|---|
| 3-14-73 | | | 2.02 | | | |
| 3-21-73 | | 2.78 | 2.36 | | | |
| 3/29-73 | | 2.61 | 1.99 | 2.22 | 2.05 | 2.07 |
| 4-7 -73 | 2.12 | 2.56 | 1.94 | 1.99 | 2.01 | 1.92 |
| 4-12-73 | 2.09 | 2.07 | 1.88 | 1.99 | 1.68 | 1.93 |
| 4-19-73 | 2.13 | 2.64 | 1.91 | 2.00 | 1.84 | 1.94 |
| 4-26-73 | 2.07 | 2.60 | 1.93 | 1.91 | .87 | 1.89 |
| 5-10-73 | 2.13 | 2.51 | 1.88 | 1.99 | 1.80 | 1.96 |
| 6-14-73 | 2.07 | 2.43 | 1.81 | 1.90 | 1.82 | 1.90 |
| 7-12-73 | 2.10 | 2.12 | 1.86 | 1.88 | 1.79 | 1.90 |
| 8-16-73 | 2.09 | 2.24 | 1.90 | 1.86 | 1.77 | 1.85 |
| 9-13-73 | | | | | | |
| 10-18-73 | 2.07 | 2.38 | 1.70 | 1.91 | 1.73 | 1.84 |
| 11-15-73 | | | | | | |
| 12-13-73 | 2.10 | 2.49 | 1.72 | 1.80 | 1.75 | 1.92 |
| 1-17-74 | | | | | | |
| 2-14-74 | 1.99 | 2.22 | 1.75 | | 1.73 | 1.82 |
| 3-13-74 | | | | | | |
| 4-19-74 | 2.13 | 2.32 | 1.72 | | | 1.67 |

Table 3. Regression of leaf area (AR) on leaf fresh weight (FW), leaf dry weight (DW), leaf length (LH) and leaf width (WD) for 6 citrus cultivars.

| | Intercept | Slope | Correlation number (r)$^z$ |
|---|---|---|---|
| AR vs FW | | | |
| Murcott | 3.053 | 19.867 | 0.788** |
| Temple | - 2.362 | 36.989 | 0.757** |
| Marsh | 3.321 | 21.250 | 0.946** |
| Hamlin | 2.336 | 23.955 | 0.985** |
| Pineapple | 2.023 | 22.488 | 0.969** |
| Valencia | 11.594 | 12.427 | 0.699** |
| AR vs DW | | | |
| Murcott | 6.466 | 33.732 | 0.731** |
| Temple | 0.640 | 81.103 | 0.921** |
| Marsh | 15.467 | 28.519 | 0.802** |
| Hamlin | 7.258 | 58.883 | 0.923** |
| Pineapple | 9.367 | 49.289 | 0.877** |
| Valencia | 8.463 | 47.952 | 0.879** |
| AR vs LH | | | |
| Murcott | - 5.383 | 2.720 | 0.815** |
| Temple | -11.133 | 3.409 | 0.777** |
| Marsh | -20.803 | 5.623 | 0.865** |
| Hamlin | -17.129 | 4.928 | 0.962** |
| Pineapple | -13.927 | 4.738 | 0.966** |
| Valencia | -14.161 | 4.575 | 0.972** |
| AR vs WD | | | |
| Murcott | - 4.357 | 5.330 | 0.792** |
| Temple | - 5.947 | 6.046 | 0.796** |
| Marsh | -16.003 | 9.225 | 0.980** |
| Hamlin | -11.150 | 8.020 | 0.968** |
| Pineapple | -10.116 | 7.687 | 0.981** |
| Valencia | -10.781 | 7.833 | 0.968** |

$^z$Significant at 1% (**).

relationships. It should also be emphasized that while Turrell used a random sample of variously aged leaves from the tree canopy at a single sampling date, sampling for this research was made from spring flush leaves at several times during the year. This difference in sampling procedure might have some effect on the relationships described above and this possibility should be investigated.

The very high correlation coefficient found here and by Turrell (170) for citrus using simple linear and logarithmic relationships would indicate that good leaf area estimates could be made without using multiple correlation techniques. For some plants, it has been shown that multiple correlations are more accurate. An extensive study with tea by Fordham (62) showed a logarithmic regression of leaf area on leaf width and leaf length. He stated, however, that the use of a simple linear correlation would considerably simplify field assessment, although it has been demonstrated that this could lead to a marked loss of accuracy. Such a loss might be acceptable where only a gross estimate of total area is desired, as for example in the calculation of leaf area indices. In such cases leaf length would be the simplest to record. Based on the data reported here, a similar conclusion might be made. For gross estimates of total leaf area of citrus, a simple correlation between leaf length and area, using a linear regression might be satisfactory.

Differential NK treatments influenced the growth of 'Valencia' orange leaves. The general growth pattern for leaves in this experiment (Figs. 6, 7, 8, 9 and Table 4) was the same as that for 'Valencia' leaves in the cultivar experiment. NFL and FL, however, were larger at the higher rates of N fertilization than at lower rates. AR was

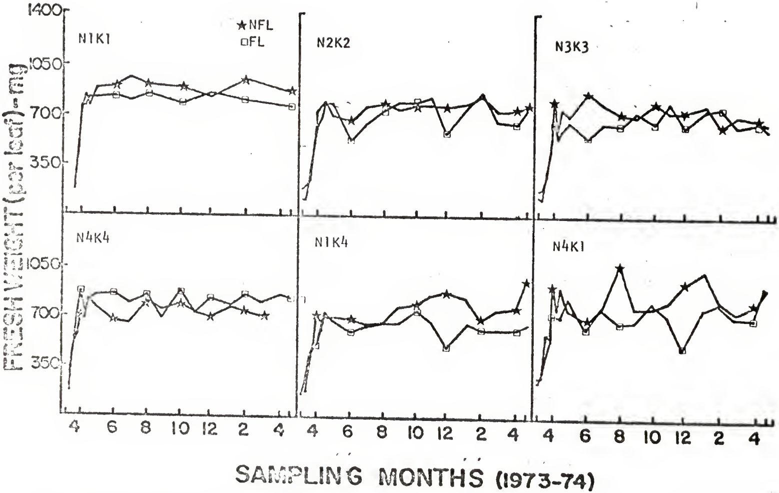

Fig. 6. Fresh weight of leaves from non-fruiting stems (NFL) and fruiting stems (FL) of 'Valencia' orange at varying levels of N and K fertilization.

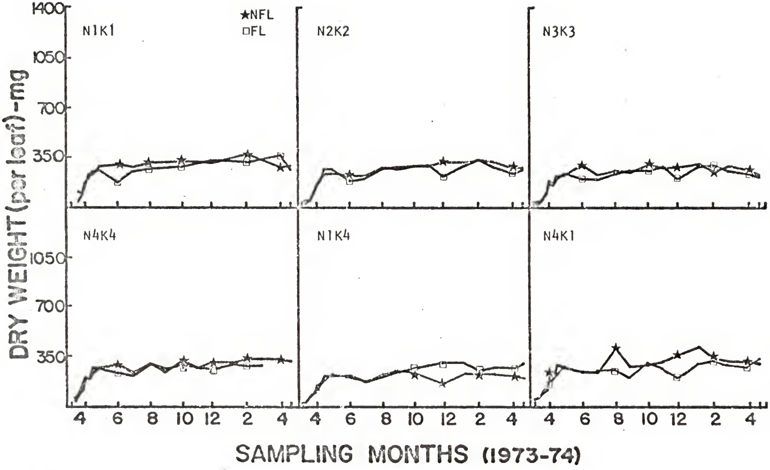

Fig. 7. Dry weight of leaves from non-fruiting stems (NFL) and fruiting stems (FL) of 'Valencia' orange at different levels of N and K fertilization.

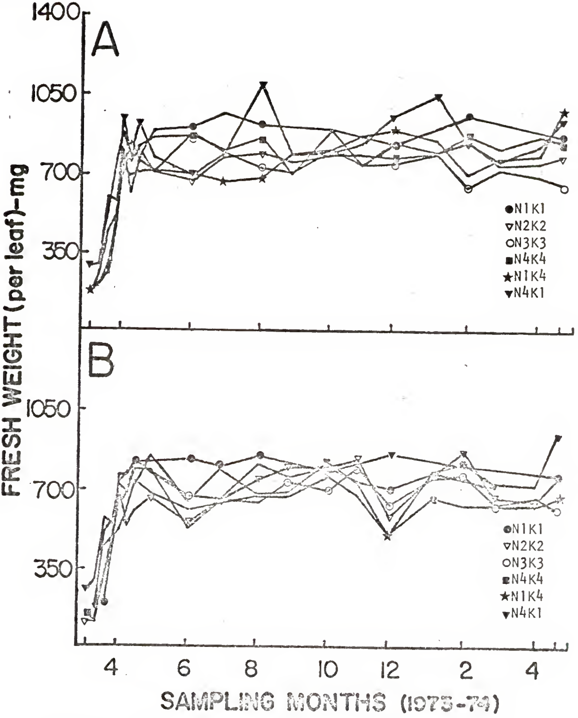

Fig. 8A. Comparisons of fresh weight of leaves from non-fruiting stems (NFL) of 'Valencia' orange at different levels of N and K fertilization.

Fig. 8B. Comparisons of fresh weight of leaves from fruiting stems (FL) of 'Valencia' orange at different levels of N and K fertilization.

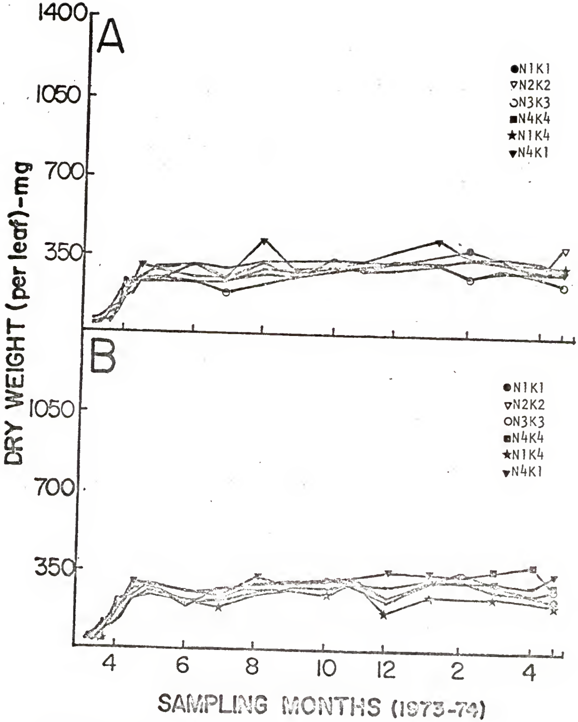

Fig. 9A. Comparisons of dry weight of leaves from non-fruiting stems (NFL) of 'Valencia' orange at varying levels of N and k fertilization.

Fig. 9B. Comparisons of dry weight of leaves from fruiting stems (FL) of 'Valencia' orange at different levels of N and K fertilization.

Table 4. Fresh weight (FW), dry weight (DW), length (LH), width (WD) and area of leaves from non-fruiting stems (NFL) and fruiting stems (FL) of 'Valencia' orange leaves at varying rates of N and K fertilization.

| Treatment | Leaf type | FW (mg) | DW (mg) | LH (cm) | WD (cm) | AR ($cm^2$) |
|---|---|---|---|---|---|---|
| N1K1 | NFL | 772.0 | 271.0 | 7.59 | 4.04 | 21.67 |
| | FL | 720.0 | 240.0 | 7.04 | 3.69 | 18.75 |
| N2K2 | NFL | 657.0 | 226.0 | 7.38 | 3.92 | 21.18 |
| | FL | 621.05 | 215.0 | 6.90 | 3.61 | 16.12 |
| N3K3 | NFL | 634.0 | 214.0 | 7.16 | 3.81 | 19.56 |
| | FL | 591.62 | 196.05 | 6.56 | 3.47 | 16.80 |
| N4K4 | NFL | 763.0 | 257.0 | 7.91 | 4.19 | 22.22 |
| | FL | 679.31 | 239.21 | 7.20 | 3.72 | 18.13 |
| N1K4 | NFL | 670.0 | 211.0 | 7.36 | 3.82 | 19.75 |
| | FL | 588.36 | 192.49 | 6.68 | 3.41 | 15.50 |
| N4K1 | NFL | 761.0 | 262.0 | 7.88 | 4.18 | 23.83 |
| | FL | 658.57 | 232.08 | 7.15 | 3.79 | 19.77 |

highest in N4K1 and N4K4 and lowest in N1K1 and N1K4. There was no readily apparent relationship between K fertilization and leaf size. Later discussion comparing %DW K and leaf size provide additional clarification of this point.

AR of NFL was highly correlated with FW, DW, LH and WD (Table 5) as with 'Valencia' in the cultivar study. Comparison of the slope of the regression equations indicates certain trends in the effect of NK fertilization on leaf characters. For the AR and FW regression, a large increase in FW results in a smallest increase in AR at the lowest level of K fertilization and vice versa as shown by the slopes of the regression equations which were 12.43 for N1K1 and 29.70 for N1K4. This would indicate that higher K fertilization would cause the development of leaves of lower FW and consequently containing less water. Low K levels would cause the development of leaves containing more water. For the AR and DW regression, a large increase in DW results in the smallest increase in AR at the highest levels of N fertilization and vice versa as indicated by the slopes of the regression equations of 36.50 for N4K4 and 51.55 for N1K4, indicating that leaves developed under high N conditions would be thicker, heavier or denser than those produced under low N conditions.

### Fruit

Fruit fresh weight (FW), fruit dry weight (DW) and fruit volume (V) for the 6 citrus cultivars are shown in Fig. 11. Table 6 shows data for FW, DW, V, density (DN), length (L), diameter (D) and D/L ratio for the 6 cultivars.

Fruit growth followed a sigmoid curve as defined by Bain (8), showing 3 distinct stages of growth: stage I, a period of rapid

Table 5. Regression of leaf area (AR) on leaf fresh weight (FW), leaf dry weight (DW), leaf length (LH) and leaf width (WD) at different rates of N and K fertilization.

| | Intercept | Slope | Correlation number (r) |
|---|---|---|---|
| AR vs FW | | | |
| N1K1 | 11.594 | 12.427 | 0.699 ** |
| N2K2 | 0.206 | 29.575 | 0.945 ** |
| N3K3 | - 0.363 | 29.161 | 0.950 ** |
| N4K4 | - 7.245 | 37.306 | 0.891 ** |
| N1K4 | - 1.154 | 29.707 | 0.897 ** |
| N4K1 | - 0.110 | 28.934 | 0.926 ** |
| AR vs DW | | | |
| N1K1 | 8.463 | 47.952 | 0.880 ** |
| N2K2 | 9.860 | 46.032 | 0.852 ** |
| N3K3 | 9.777 | 41.866 | 0.721 ** |
| N4K4 | 12.458 | 36.499 | 0.674 ** |
| N1K4 | 8.432 | 51.554 | 0.876 ** |
| N4K1 | 13.069 | 36.355 | 0.720 ** |
| AR vs LH | | | |
| N1K1 | -14.182 | 4.571 | 0.977 ** |
| N2K2 | -18.666 | 5.172 | 0.966 ** |
| N3K3 | -19.969 | 5.279 | 0.969 ** |
| N4K4 | -16.716 | 4.835 | 0.819 ** |
| N1K4 | -19.509 | 5.159 | 0.939 ** |
| N4K1 | -10.377 | 4.109 | 0.884 ** |
| AR vs WD | | | |
| N1K1 | - 9.225 | 7.360 | 0.952 ** |
| N2K2 | -12.552 | 8.168 | 0.983 ** |
| N3K3 | -14.136 | 8.423 | 0.959 ** |
| N4K4 | -14.514 | 8.559 | 0.805 ** |
| N1K4 | -11.735 | 7.938 | 0.941 ** |
| N4K1 | -14.827 | 8.689 | 0.881 ** |

[z] Significant at 1% (**).

cell division; Stage II, a period of rapid growth in size due to cell enlargement; Stage III, during which changes occur in brix, acid, color and flavor which lead to commercial maturity of the fruit. Sampling in this study started at approximately the end of stage I of fruit growth as defined by Bain and the data on Fig. 11 shows only Stage II and Stage III. There was a considerable variability between cultivars in the date for the termination of Stage II and the beginning of stage III. This date was not related to the time of fruit maturity. The cultivars can be divided into 2 general groups in respect to fruit growth and maturity. The first group, consisting of 'Hamlin' orange and 'Marsh' grapefruit includes cultivars whose fruit reaches minimum commercial brix/acid ratio soon after reaching maximum size at the end of stage II. The second group, consisting of 'Pineapple' orange, 'Valencia' orange, 'Temple' orange and 'Murcott' mandarin, includes cultivars whose fruit requires a period of at least 2 months during stage III for fruit maturation. 'Marsh' grapefruit, for example, reached maximum size in December, and was mature at that time, even though it was not harvested until March. 'Valencia' orange fruit began stage III of fruit growth in December but did not reach minimum commercial maturity until March.

The rate of increases in FW, DW and DN show differences between cultivars (Fig. 11, Table 6). Certain cultivars produced fruit which was more dense than others. The fruit of 'Murcott' mandarin has higher density than fruit of all other cultivars. The 'Marsh' grapefruit had the lowest density. 'Temple' orange, 'Hamlin' orange, 'Pineapple' orange and 'Valencia' orange were intermediate and of the same density. The density of all cultivars with the exception

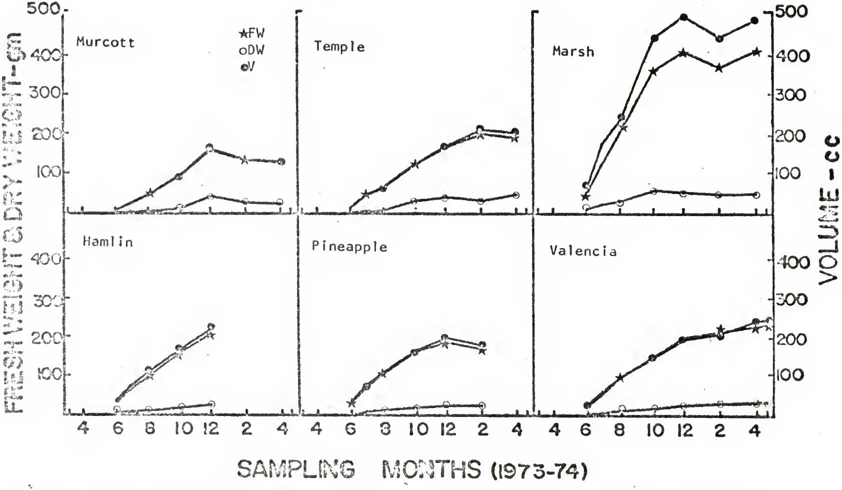

Fig. 11. Fruit volume (V), dry weight (DW) and fresh weight (FW) for 6 citrus cultivars.

Table 6. Fresh weight (FW), dry weight (DW), volume (V), density (DN), diameter (D), length (L) and D/L ratio of fruit of 6 citrus cultivars.

| MURCOTT | Volume | | FW | | DW | | Diam | | LH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cc | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density | D/L |
| 6-14-73 | 7.50 | | 7.52 | | 1.53 | | 2.36 | | 2.11 | | 1.00 | 1.12 |
| 7-12-73 | 24.75 | 230 | 24.82 | 230 | 4.30 | 181 | 3.78 | 60 | 3.16 | 50 | 1.00 | 1.20 |
| 8-16-73 | 45.75 | 84 | 45.55 | 83 | 6.20 | 44 | 4.59 | 21 | 3.56 | 13 | .99 | 1.28 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 94.00 | 105 | 94.90 | 108 | 12.58 | 103 | 5.89 | 28 | 4.61 | 29 | 1.00 | 1.28 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 154.50 | 64 | 159.75 | 68 | 41.70 | 231 | 6.88 | 17 | 4.92 | 7 | 1.03 | 1.40 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 130.50 | -15 | 132.20 | -17 | 25.98 | -38 | 6.43 | -6 | 4.81 | -2 | 1.01 | 1.34 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | 125.25 | - 4 | 127.70 | - 3 | 23.38 | -10 | 6.23 | -3 | 4.56 | -5 | 1.02 | 1.37 |
| 5- 8-74 | | | | | | | | | | | | |
| TEMPLE | | | | | | | | | | | | |
| 6-14-73 | 15.25 | | 14.45 | | 2.70 | | 2.97 | | 3.10 | | .95 | .96 |
| 7-12-73 | 47.50 | 211 | 44.00 | 204 | 7.10 | 204 | 4.50 | 52 | 4.28 | 38 | .92 | 1.05 |
| 8-16-73 | 67.25 | 41 | 63.67 | 45 | 8.70 | 22 | 4.80 | 7 | 4.75 | 11 | .95 | 1.01 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 124.00 | 84 | 122.13 | 92 | 32.75 | 282 | 6.25 | 30 | 5.77 | 21 | .98 | 1.08 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 167.50 | 35 | 163.65 | 34 | 40.55 | 24 | 6.82 | 8 | 5.83 | 1 | .98 | 1.17 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 206.50 | 23 | 195.95 | 20 | 47.94 | 18 | 7.32 | 7 | 6.21 | 6 | .95 | 1.18 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | 197.50 | -4 | 186.00 | -5 | 33.88 | -33 | 6.97 | -5 | 5.91 | -5 | .94 | 1.18 |

Table 6 - continued

| MARSH | Volume | | FW | | DW | | Diam | | LH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cc | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density | D/l |
| 6-14-73 | 64.50 | | 48.66 | | 12.08 | | 4.88 | | 4.78 | | .75 | 1.02 |
| 7-12-73 | 172.50 | 167 | 122.10 | 151 | 23.43 | 94 | 6.77 | 38 | 6.47 | 35 | .70 | 1.05 |
| 8-16-73 | 230.50 | 34 | 199.28 | 63 | 30.90 | 32 | 7.63 | 13 | 7.08 | 9 | .86 | 1.08 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 434.00 | 88 | 352.90 | 77 | 58.15 | 88 | 9.51 | 25 | 8.66 | 22 | .81 | 1.10 |
| 11-15 | | | | | | | | | | | | |
| 12-13-73 | 487.25 | 12 | 398.80 | 13 | 51.73 | -11 | 9.72 | 2 | 8.76 | 1 | .82 | 1.12 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 435.00 | -11 | 359.90 | -10 | 47.20 | - 9 | 9.39 | - 3 | 8.38 | - 4 | .83 | 1.12 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | 479.00 | 10 | 402.10 | 12 | 50.54 | 7 | 9.43 | 0 | 8.40 | 0 | .84 | 1.12 |
| 5-08-74 | | | | | | | | | | | | |
| HAMLIN | | | | | | | | | | | | |
| 6-14-73 | 37.00 | | 32.28 | | 7.10 | | 4.05 | | 3.87 | | .87 | 1.05 |
| 7-12-73 | 72.25 | 95 | 64.82 | 100 | 10.08 | 42 | 5.11 | 26 | 4.58 | 18 | .90 | 1.11 |
| 8-16-73 | 104.62 | 45 | 94.28 | 45 | 11.35 | 13 | 5.55 | 9 | 5.42 | 18 | .90 | 1.02 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 164.00 | 57 | 155.60 | 65 | 19.13 | 68 | 6.76 | 22 | 6.48 | 20 | .95 | 1.04 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 212.00 | 29 | 200.40 | 28 | 26.63 | 39 | 7.24 | 7 | 6.92 | 7 | .94 | 1.05 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | | | | | | | | | | | | |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | | | | | | | | | | | | |
| 5-08-74 | | | | | | | | | | | | |

Table 6 - continued

| PINEAPPLE | Volume | | FW | | DW | | Diam | | LH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cm | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density | D/L |
| 6-14-73 | 35.50 | | 31.45 | | 7.13 | | 4.00 | | 3.73 | | .88 | 1.07 |
| 7-12-73 | 75.00 | 111 | 68.15 | 117 | 11.10 | 88.2 | 5.17 | 33 | 4.58 | 23 | .91 | 1.13 |
| 8-16-73 | 107.65 | 44 | 102.28 | 50 | 14.32 | 29 | 5.72 | 10 | 5.31 | 16 | .95 | 1.08 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 161.50 | 50 | 157.66 | 54 | 20.43 | 43 | 6.77 | 18 | 6.33 | 19 | .98 | 1.07 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 190.00 | 18 | 179.40 | 38 | 25.15 | 24 | 6.90 | 2 | 6.17 | - 2 | .94 | 1.12 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 172.00 | - 9 | 162.45 | - 9 | 24.20 | - 4 | 6.87 | 0 | 6.25 | + 1 | .94 | 1.10 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | | | | | | | | | | | | |
| 5-08-74 | | | | | | | | | | | | |
| VALENCIA | | | | | | | | | | | | |
| 6-14-73 | 28.75 | | 25.81 | | 5.38 | | 3.67 | | 3.66 | | .90 | 1.00 |
| 7-12-73 | 59.75 | 107 | 54.42 | 111 | 9.85 | 83 | 4.75 | 29 | 4.69 | 28 | .91 | 1.01 |
| 8-16-73 | 93.25 | 56 | 94.41 | 73 | 14.00 | 42 | 5.47 | 15 | 5.40 | 15 | 1.01 | 1.01 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 145.00 | 55 | 141.40 | 50 | 19.58 | 40 | 6.42 | 17 | 6.22 | 15 | .98 | 1.03 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 193.30 | 33 | 186.65 | 32 | 27.48 | 40 | 6.92 | 8 | 6.63 | 7 | .96 | 1.04 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 206.50 | 7 | 200.38 | 7 | 31.78 | 17 | 7.13 | 3 | 6.82 | 3 | .97 | 1.04 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | 220.50 | 7 | 234.13 | 17 | 32.78 | 3 | 7.04 | - 1 | 6.69 | - 2 | 1.06 | 1.05 |
| 5-08-74 | | | | | | | | | | | | |

of 'Marsh' grapefruit was constant throughout the sampling period. 'Marsh' grapefruit decreased in density until August and then increased until harvest.

Results of this research shows that FW increased more rapidly than DW in stage II for all cultivars (Fig. 11 and Table 6). Conversely, DW increased more rapidly than FW during stage III. These results during stage II agree with previously reported data of Hassaballa (77) on 'Washington' navel orange, 'Orlando' tangelo and 'Parson Brown' orange. These differences in growth rates indicate that stage II is a period of extremely rapid water incorporation into the fruit while stage III is a period of rapid synthesis of metabolites in the fruit tissues or that high rates of translocation of such materials occurs at this time.

D/L ratio (Table 6) showed that orange fruit were essentially round from fruit set to harvest (D/L ratio approximately 1). 'Marsh' grapefruit, 'Murcott' mandarin and 'Temple' orange fruits were essentially round in the beginning but developed a flattened shape during the latter stages of growth (D/L ratio greater than 1 and increasing).

FW, DW and LH of the 'Valencia' fruit from the NK study (Fig. 12 and Table 7) followed the same patterns of increase as previously described for 'Valencia' orange in the cultivar study (Fig. 11 and Table 6). There were differences in FW, DW, V, D and LH due to levels of NK fertilization. The combination of high K and low N in the N1K4 treatment produced the largest fruit. Low K and high N (N4K1) produced the smallest fruit. Other NK combinations were intermediate. These results are in agreement with other workers (21, 94, 120, 123,

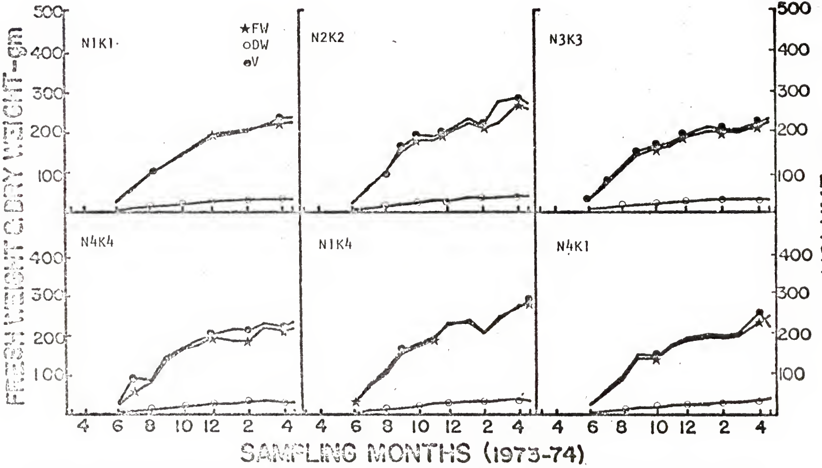

Fig. 12. Fruit volume (V), dry weight (DW) and fresh weight (FW) of 'Valencia' orange fruit produced by trees fertilized at different NK rates.
]

Table 7. Fresh weight (FW), dry weight (DW), volume (V), density (DN), diameter (D), length (L) and D/L ratio of 'Valencia' orange fruit produced by trees fertilized at varying rates of N and K fertilization

| N1K1 | Volume | | FW | | DW | | Diam | | LH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cc | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density | D/L |
| 6-14-73 | 28.75 | | 25.81 | | 5.38 | | 3.67 | | 3.66 | | .90 | 1.00 |
| 7-12-73 | 59.75 | 107 | 54.42 | 111 | 9.85 | 83 | 4.75 | 29 | 4.69 | 28 | .91 | 1.01 |
| 8-16-73 | 93.25 | 56 | 94.41 | 73 | 14.00 | 42 | 5.47 | 15 | 5.40 | 15 | 1.01 | 1.01 |
| 9-13-73 | | | | | | | | | | | | |
| 10-18-73 | 145.00 | 55 | 141.40 | 50 | 19.58 | 40 | 6.42 | 17 | 6.22 | 15 | .98 | 1.03 |
| 11-15-73 | | | | | | | | | | | | |
| 12-13-73 | 193.30 | 33 | 186.65 | 32 | 27.48 | 40 | 6.92 | 8 | 6.63 | 7 | .96 | 1.04 |
| 1-17-74 | | | | | | | | | | | | |
| 2-14-74 | 206.50 | 7 | 200.38 | 7 | 31.78 | 17 | 7.13 | 3 | 6.82 | 3 | .97 | 1.04 |
| 3-13-74 | | | | | | | | | | | | |
| 4-19-74 | 220.50 | 7 | 234.13 | 17 | 32.78 | 3 | 7.04 | - 1 | 6.69 | - 2 | 1.06 | 1.05 |
| 5-8- 74 | | | | | | | | | | | | |
| N2K2 | | | | | | | | | | | | |
| 6-14-73 | 24.50 | | 21.86 | | 6.53 | | 3.49 | | 3.51 | | .89 | .99 |
| 7-12-73 | 62.00 | 153 | 57.17 | 161 | 9.98 | 53 | 4.79 | 37 | 4.99 | 42 | .92 | .96 |
| 8-16-73 | 99.00 | 60 | 99.78 | 75 | 14.84 | 47 | 5.62 | 13 | 5.35 | 7 | 1.01 | 1.05 |
| 9-13-73 | 158.50 | 60 | 145.90 | 46 | 19.91 | 34 | 6.59 | 17 | 6.58 | 23 | .92 | 1.00 |
| 10-18-73 | 191.00 | 21 | 179.15 | 23 | 24.00 | 20 | 6.79 | 3 | 6.73 | 2 | .94 | 1.01 |
| 11-15-73 | 187.50 | - 2 | 177.70 | 0 | 30.25 | 26 | 6.95 | 2 | 6.74 | 0 | .95 | 1.03 |
| 12-13-73 | 201.50 | 7 | 194.40 | 9 | 27.84 | - 8 | 6.61 | - 5 | 6.11 | -9 | .96 | 1.08 |
| 1-17-74 | 231.00 | 15 | 219.95 | 13 | 36.83 | 32 | 7.03 | 6 | 6.66 | 9 | .95 | 1.06 |
| 2-14-74 | 213.50 | - 8 | 207.65 | - 6 | 33.71 | - 8 | 7.19 | 2 | 6.80 | 2 | .97 | 1.06 |
| 3-13-74 | 273.50 | 28 | 221.10 | 6 | 37.35 | 11 | 7.84 | 9 | 7.16 | 5 | .81 | 1.09 |
| 4-19-74 | 283.00 | 3 | 266.12 | 20 | 40.00 | 7 | 7.51 | - 4 | 7.34 | 2 | .94 | 1.02 |
| 5-08-74 | 268.50 | - 5 | 254.25 | - 4 | 39.10 | - 2 | 7.53 | 0 | 7.26 | 1 | .95 | 1.04 |

Table 7 - continued

| N3K3 | Volume | | FW | | DW | | Diam | | LH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cc | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density | D/L |
| 6-14-73 | 34.50 | | 30.65 | | 7.65 | | 3.89 | | 3.72 | | .89 | 1.05 |
| 7-12-73 | 72.00 | 109 | 61.25 | 100 | 10.88 | 42 | 5.10 | 31 | 4.95 | 33 | .85 | 1.03 |
| 8-16-73 | 150.00 | 108 | 139.65 | 128 | 18.15 | 67 | 6.47 | 66 | 6.44 | 30 | .93 | 1.00 |
| 9-13-73 | 164.75 | 10 | 156.63 | 12 | 21.05 | 16 | 6.45 | 0 | 6.36 | 1 | .95 | 1.01 |
| 10-18-73 | 171.25 | 4 | 162.95 | 4 | 24.70 | 17 | 6.77 | 5 | 6.52 | 2 | .95 | 1.04 |
| 11-15-73 | 191.50 | 12 | 185.40 | 14 | 26.70 | 8 | 6.85 | 1 | 6.51 | 0 | .97 | 1.05 |
| 12-13-73 | | | | | | | | | | | | |
| 1-17-74 | 210.00 | 10 | 198.60 | 7 | 31.05 | 16 | 6.89 | 0 | 6.89 | 6 | .95 | 1.00 |
| 2-14-74 | 203.00 | - 3 | 196.90 | 0 | 32.20 | 4 | 6.99 | 1 | 6.66 | -3 | .97 | 1.05 |
| 3-13-74 | 203.00 | 0 | 195.15 | 0 | 32.15 | 0 | 7.08 | 1 | 6.86 | 3 | .96 | 1.03 |
| 4-19-74 | 220.50 | 9 | 212.15 | 9 | 32.23 | 0 | 6.95 | -2 | 6.73 | 2 | .96 | 1.03 |
| 5-08-74 | 232.00 | 5 | 221.60 | 4 | 30.13 | - 6 | 7.07 | 2 | 6.85 | 2 | .96 | 1.03 |
| N4K4 | | | | | | | | | | | | |
| 6-14-73 | 39.75 | | 26.10 | | 6.75 | | 3.74 | | 3.58 | | .88 | 1.04 |
| 7-12-73 | 61.00 | 105 | 55.14 | 111 | 10.03 | 49 | 4.71 | 26 | 4.92 | 37 | .90 | .96 |
| 8-16-73 | 91.58 | 50 | 85.50 | 55 | 13.55 | 33 | 5.37 | 14 | 5.60 | 14 | .93 | .96 |
| 9-13-73 | 140.00 | 53 | 129.93 | 52 | 17.30 | 28 | 6.37 | 19 | 6.39 | 14 | .93 | 1.00 |
| 10-18-73 | 165.00 | 18 | 161.13 | 24 | 21.28 | 23 | 6.09 | - 3 | 6.42 | 0 | .98 | .95 |
| 11-15-73 | 182.50 | 11 | 170.98 | 6 | 24.68 | 16 | 6.85 | 12 | 6.15 | 5 | .94 | 1.01 |
| 12-13-73 | 197.50 | 8 | 188.90 | 10 | 28.55 | 16 | 6.88 | 0 | 6.73 | 0 | .96 | 1.02 |
| 1-17-74 | 210.00 | 6 | 179.38 | - 5 | 29.90 | 1 | 6.82 | - 1 | 6.51 | - 3 | .85 | 1.05 |
| 2-14-74 | 206.50 | - 2 | 179.65 | 0 | 34.40 | 15 | 7.03 | 3 | 6.74 | 3 | .87 | 1.04 |
| 3-13-74 | 224.50 | 9 | 213.15 | 19 | 36.40 | 6 | 7.36 | 5 | 7.06 | 5 | .95 | 1.04 |
| 4-19-74 | 216.00 | - 4 | 205.38 | - 4 | 31.14 | -14 | 6.99 | 5 | 6.78 | 24 | .95 | 1.03 |
| 5-08-74 | 228.50 | 6 | 212.90 | 4 | 32.70 | 5 | 6.92 | -1 | 6.87 | 13 | .93 | 1.01 |

Table 7 - continued

| N1K4 | Volume |  | FW |  | DW |  | Diam |  | LH |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of sampling | cc | growth rate (%) | mgs | growth rate (%) | mgs | growth rate (%) | cm | growth rate (%) | cm | growth rate (%) | Density (FW/VOL) | D/L |
| 6-14-73 | 30.00 |  | 26.43 |  | 4.85 |  | 3.73 |  | 3.68 |  | .88 | 1.01 |
| 7-12-73 | 76.00 | 153 | 68.78 | 160 | 12.18 | 151 | 5.16 | 38 | 5.16 | 40 | .90 | 1.00 |
| 8-16-73 | 112.82 | 48 | 103.53 | 51 | 14.30 | 17 | 5.62 | 9 | 5.64 | 9 | .92 | 1.00 |
| 9-13-73 | 159.00 | 41 | 148.15 | 43 | 17.80 | 24 | 6.69 | 19 | 6.46 | 14 | .93 | 1.04 |
| 10-18-73 | 174.50 | 10 | 168.50 | 14 | 22.25 | 25 | 6.70 | 0 | 6.52 | 1 | .96 | 1.03 |
| 11-15-73 | 190.00 | 9 | 180.98 | 7 | 30.05 | 35 | 6.93 | 3 | 6.85 | 5 | .95 | 1.01 |
| 12-13-73 | 220.50 | 16 | 226.53 | 25 | 30.06 | 0 | 7.21 | 4 | 6.94 | 1 | 1.03 | 1.04 |
| 1-17-74 | 232.50 | 5 | 224.10 | - 1 | 34.48 | 15 | 7.15 | 0 | 6.75 | -3 | .96 | 1.06 |
| 2-14-74 | 202.00 | - 13 | 199.15 | 11 | 31.95 | 7 | 7.02 | - 2 | 6.67 | - 1 | .98 | 1.05 |
| 3-13-74 | 242.00 | 19 | 234.40 | 18 | 37.80 | 18 | 7.52 | 7 | 7.32 | 10 | .97 | 1.03 |
| 4-19-74 | 264.00 | 9 | 270.35 | 15 | 38.90 | 3 | 7.39 | - 2 | 7.33 | 0 | 1.02 | 1.01 |
| 5-08-74 | 283.50 | 7 | 268.68 | 0 | 34.95 | - 10 | 7.10 | - 4 | 6.86 | - 6 | .95 | 1.03 |
| N4K1 |  |  |  |  |  |  |  |  |  |  |  |  |
| 6-14-73 | 27.75 |  | 25.35 |  | 5.84 |  | 3.61 |  | 3.81 |  | .91 | .95 |
| 7-12-73 | 60.50 | 118 | 53.70 | 112 | 10.33 | 77 | 4.63 | 282 | 4.90 | 29 | .89 | .95 |
| 8-16-73 | 99.00 | 64 | 90.03 | 68 | 13.45 | 30 | 5.33 | 15 | 5.45 | 11 | .91 | .98 |
| 9-13-73 | 146.50 | 48 | 136.90 | 52 | 19.00 | 41 | 6.39 | 20 | 6.43 | 19 | .93 | .99 |
| 10-18-73 | 142.00 | - 3 | 136.98 | 0 | 19.35 | 2 | 6.16 | - 3 | 6.11 | -05 | .96 | 1.01 |
| 11-15-73 | 170.00 | 20 | 166.48 | 22 | 25.40 | 33 | 6.81 | 7 | 6.56 | 07 | .98 | 1.04 |
| 12-13-73 | 188.00 | 11 | 180.40 | 8 | 27.48 | 8 | 6.73 | 1 | 6.61 | 01 | .96 | 1.02 |
| 1-17-74 | 197.00 | 5 | 188.65 | 4 | 29.55 | 7 | 6.67 | 0 | 6.44 | -02 | .96 | 1.04 |
| 2-14-74 | 192.50 | - 2 | 186.40 | 1 | 32.28 | 9 | 6.89 | 3 | 6.50 | 01 | .97 | 1.06 |
| 3-13-74 | 200.00 | 4 | 192.15 | 3 | 32.88 | 2 | 7.13 | 3 | 6.81 | 05 | .96 | 1.05 |
| 4-19-74 | 250.50 | 25 | 243.18 | 26 | 38.38 | 17 | 6.85 | - 4 | 6.67 | 02 | .97 | 1.03 |
| 5-08-74 | 215.00 | -14 | 204.93 | -16 | 41.68 | 9 | 7.57 | 10 | 7.02 | 05 | .95 | 1.08 |

125, 126, 127, 159) who reported that increases in N fertilization reduced fruit size while increases in K increased fruit size.

## Seasonal Changes in Mineral Element Content of Fruit and Leaves of Six Citrus Cultivars

### Changes in Mineral Element Content During the Growing Season

Amount of the mineral elements under study for the 6 cultivars are shown in Figs. 13 through 22. Data are reported for leaves from non-fruiting (NFL) and fruiting stems (FL) and for fruit (FRT) on both the %DW and absolute amount bases in order to evaluate whether changes in dry weight of the tissues are masking changes in mineral element content. Comparisons and observations will be made using both types of data. Complete data on %DW amounts is shown in Table 8.

### Nitrogen

%DW of N in NFL and FL was at a high level early in the season (Fig. 13) when the leaves are small and expanding. N then decreased and reached a minimum level during April or May. N level then increased reaching a maximum level during the summer months, after which it decreased gradually. In most instances, there was a slight increase in N during the winter months. These changes in summer, fall and winter may have resulted from summer and fall fertilization. In late winter there was a decrease associated with the beginning of new vegetative and reproductive growth on the tree. The time at which maximum and minimum levels of N were found in the NFL and FL of a particular cultivar always occur at the same time. In the FRT, %DW N started high and decreased slowly throughout the year for all cultivars. There were no differences between %DW N amounts of the

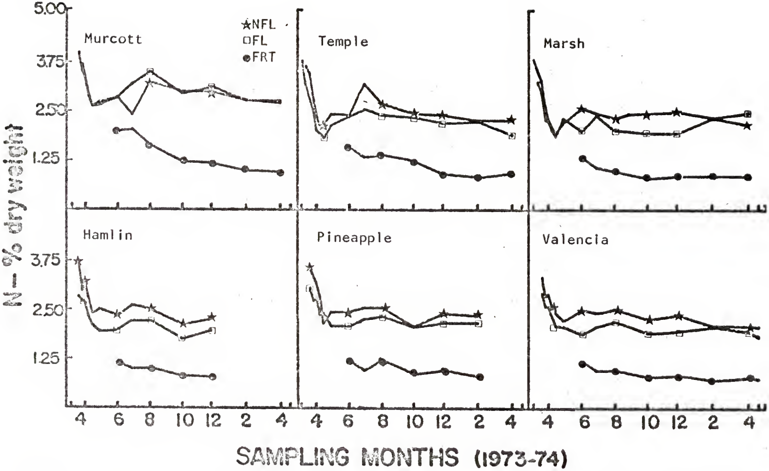

Fig. 13. N content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

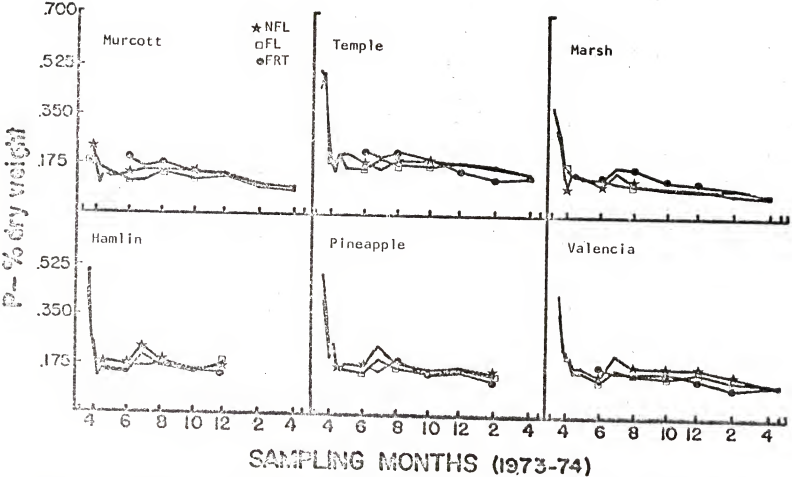

Fig. 14. P content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

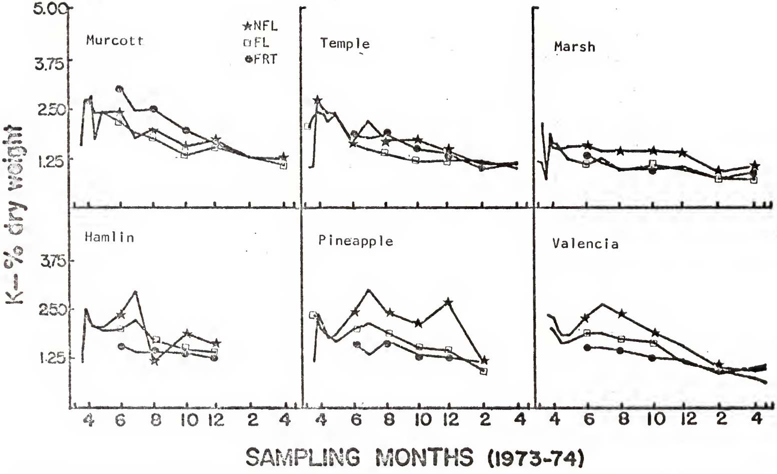

Fig. 15. K content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

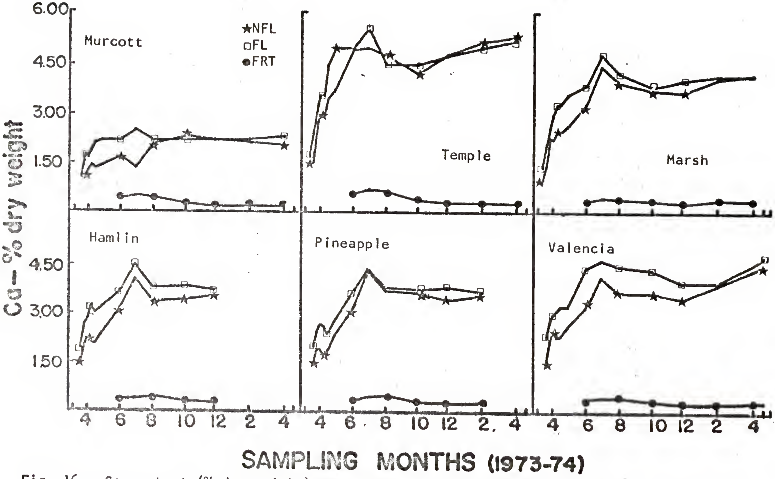

Fig. 16. Ca content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

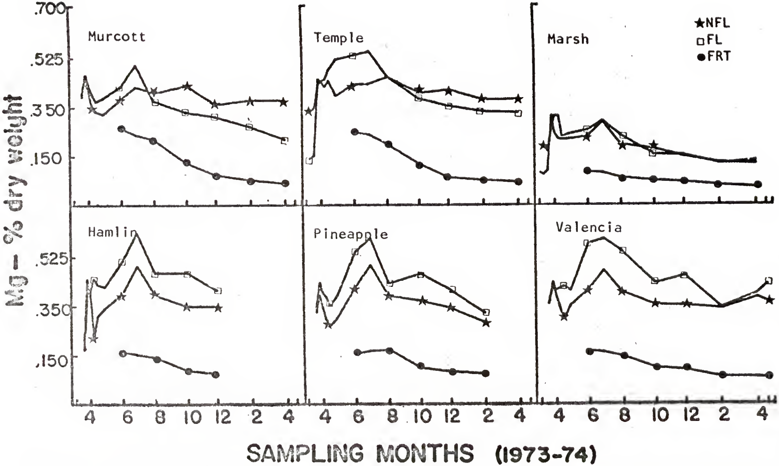

Fig. 17. Mg content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

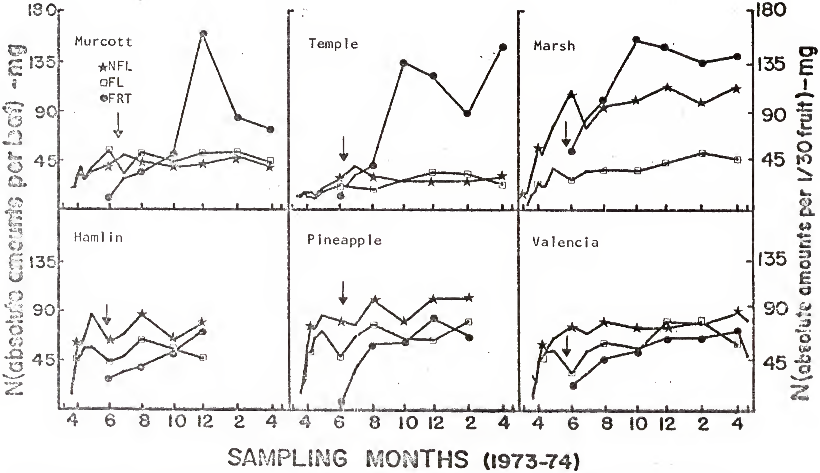

Fig. 18. N content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus. Depression in amounts due to early fruit growth indicated by ↓.

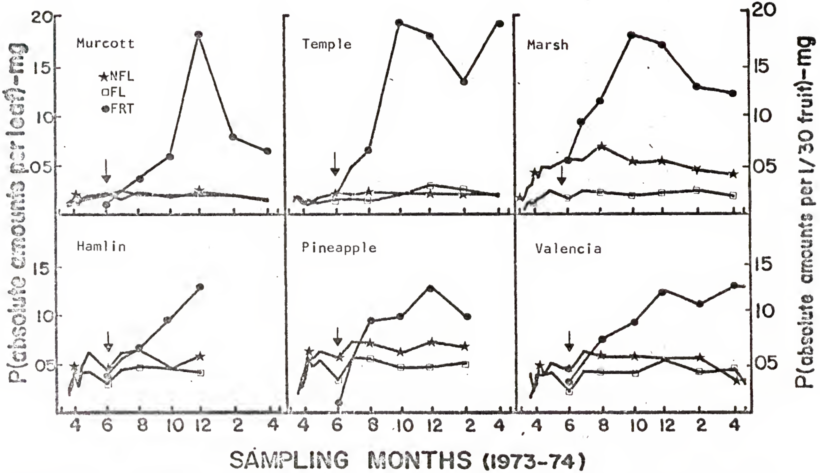

Fig. 19. P content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars. Depression in amounts due to early fruit growth indicated by ↓.

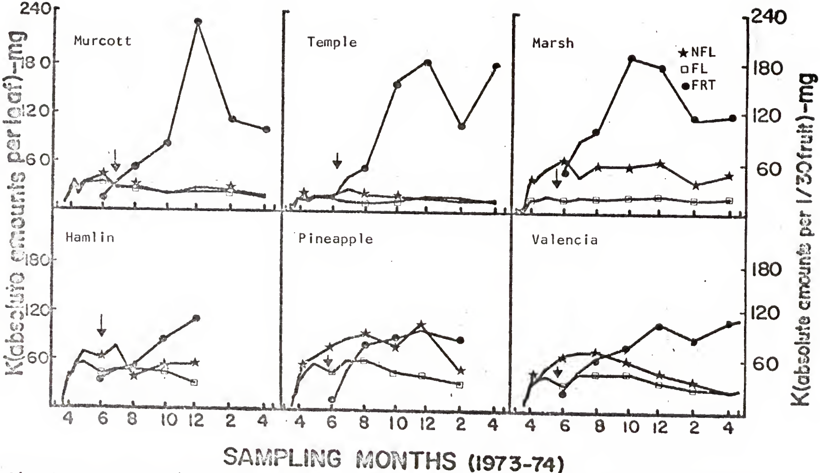

Fig. 20. K content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars. Depression in amounts due to early fruit growth indicated by ↓.

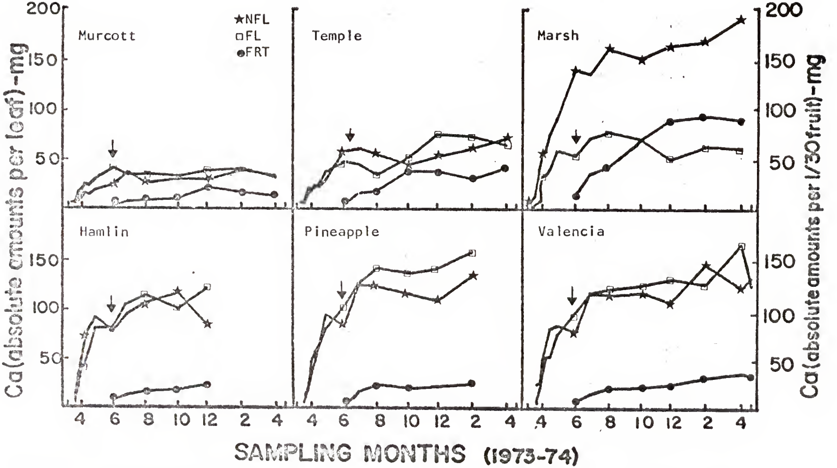

Fig. 21. Ca content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars. Depression in amounts due to early fruit growth indicated by ↓ .

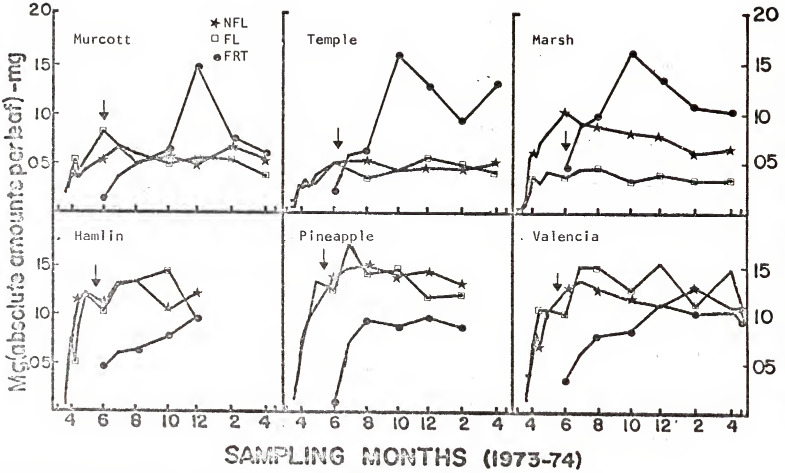

Fig. 22. Mg content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars. Depression in amounts due to early fruit growth indicated by ↓.

mature FRT of the 6 cultivars although %DW N was higher in some cultivars early in the growth of the fruit.

The absolute amount of N (Fig. 18) varies from the %DW data in several important respects. First, absolute amounts in both NFL and FL started very low, increased rapidly to a fairly stable level and then increased slowly during the remainder of the growing season. There was a decrease in N content of FL in late winter associated with the beginning of new vegetative and reproductive growth. Second, in contrast to the %DW data, there was a decline in absolute amounts in the FL of all cultivars except 'Temple' which occurred during the time of early fruit growth. This decrease was also observed in NFL of 'Hamlin', 'Pineapple', 'Valencia' and 'Marsh'. Absolute amounts of N were lower in FL than in NFL for all cultivars except for 'Murcott'. This unexpected difference may be partially explained by the fact that FL of 'Murcott' were heavier than NFL (Table 1), thus each leaf contained more N. The absolute amounts of N in FRT appear very high in relation to the amounts in the leaves. This difference is due to the fact that data is reported on a per leaf or per fruit basis and the per fruit weight is much higher than the per leaf weight. The absolute amounts of N in the fruit appear to change greatly. These changes, however, should be considered as the result of difference in individual fruit sizes in the samples. There was a wide range of fruit sizes on the trees and it was difficult to select fruit of uniform size. When absolute amounts are calculated, small changes in DW of the fruit are reflected by large changes in absolute amount of N per fruit.

The change in %DW N and in absolute amounts of N have been reported previously for 'Valencia' and 'Washington' navel orange (26, 86, 157). This is the first report of such changes in the other cultivars. The decrease in %DW N content during the early stages of leaf growth has been attributed to the rapid expansion of the leaf, shown for these experiments in Figs. 5 and 10, and the rapid accumulation of carbohydrates during this time, shown in Fig. 2 and reported by other workers (26). Once full leaf size has been attained, %DW N increases due to continued assimilation of N-containing compounds in the leaf without a concurrent increase in leaf size or dry weight. Since leaf and fruit growth both require N, the amount of N in FL is reduced as compared to NFL. Further, the leaf serves as a source of N for growth in the subsequent year and is drawn upon for N to support new vegetative and reproductive growth. Thus, the seasonal changes in N content encountered here are logically explained by considering the pattern of N use in the growth of the tree. Previous workers did not detect the decrease in N content of new leaves at the time of early fruit growth as shown in this data.

### Phosphorus

%DW P (Fig. 14) in both NFL and FL started relatively high, decreased rapidly, then increased and held a very stable level until mid-winter when there was a reduction in P levels of the leaves of most cultivars. Due to the early harvest and termination of sampling on 'Hamlin', it was not possible to confirm this reduction.

Absolute amount of P (Fig. 19) started very low and increased rapidly. There was frequently a decrease in P content at the time of flowering and fruit set. P amounts were very stable following initial expansion of the leaves. The effect of early fruit growth on P amounts in the leaves were somewhat variable but clearly shown.

In 'Hamlin', 'Pineapple', and 'Valencia' there was a reduction in P in both NFL and FL following flowering and fruit set. In 'Marsh' and 'Murcott' there was a decrease in P in FL but not in NFL. In 'Temple' there was no decrease in P in either NFL or FL following flowering. Seasonal change in P has been reported (36, 86, 87) on the %DW basis for sweet orange. This is the first report on the amount of P in both types of leaves and in the fruit of different citrus cultivars.

%DW and absolute amounts of P in FL, NFL and FRT changed in much the same way as that of N.

## Potassium

%DW weight K (Fig. 15) started very low but increased very rapidly to a high level in the young, expanding leaves after which it decreased throughout the year in both NFL and FL. In mid-winter there was a marked reduction in K content of both NFL and FL. K content of FL was always lower than K content of NFL.

Absolute amounts of K (Fig. 20) were low in very young leaves and increased to higher levels in summer. A depression in K content of FL and in some cases NFL ('Marsh'), occurred following flowering and fruit set. Following the maximum levels of mid-summer, K amounts decreased gradually or remained constant.

These changes in K content have been described previously for 'Valencia' orange and 'Washington' navel orange (28, 86, 157). This is the first report of these changes in the other cultivars. The difference between the seasonal pattern of %DW N and %DW K might be attributed to a difference in utilization of the two elements. K is not needed in large amounts by the fruit during the early period of leaf expansion and is being rapidly absorbed by the root system. Therefore, there is an increase in %DW K in leaves during this time. Only when fruit growth begins is there a major demand for K by the fruit. K for the fruit is acquired by translocation of K from the leaves and also by use of newly absorbed K from the roots. The variability in K amounts in the leaves during summer, fall and winter can be directly related to the time of K fertilizer application. In acid soils, K fertilizer application rapidly increases K content of the leaves (7, 42, 129, 150, 151, 155, 156). In calcareous soils, leaf K is not related to soil exchangeable K (90, 150, 151). The lower content of K in FL has also been reported for the major sweet orange cultivars (61, 74, 103, 104, 150). Roy and Gardner (133, 134) reported a reduction of K in both type of leaves in mid-winter. This, however, is the first report of K content decreases in the leaves at the time of bloom and early fruit growth. %DW K and absolute amounts in FRT change in the same way as previously described for N and P.

Calcium

Unlike N, P, and K, %DW Ca (Fig. 16) increased throughout the year in NFL and FL, tending to stabilize during the later half of the year. The rate of increase was not the same for all cultivars. Ca content of NFL and FL of 'Murcott' was low and did not increase markedly during the year. For the other cultivars, increases in Ca content early in fruit development were sometimes interrupted by decreases in August and September and thereafter stabilized or increased slowly. %DW Ca remained quite constant throughout fruit development.

Absolute amounts of Ca (Fig. 21) in NFL and FL increased throughout the year except for a reduction at the time of bloom and fruit set. At the time of flowering and early fruit growth, Ca decrease was seen in both NFL and FL. In orange cultivars, Ca decreased only in FL. Ca increased slightly throughout fruit growth.

These changes in Ca content have been previously reported for 'Valencia' orange and 'Washington' navel orange, but have not been reported for the other cultivars. The higher leaf Ca content of some cultivars could be due to differences in fertilization practices. 'Temple' received large applications of Ca-containing super-phosphate and these applications were reflected in the high Ca contents of the leaves. All of previous reports stated that there were no changes in leaf Ca throughout the year (78, 131, 151). However, this report shows that there is a reduction at the time of bloom and fruit set.

Magnesium

Percent dry weight Mg (Fig. 17) was very low in the expanding young leaves but increased rapidly in late spring, reaching maximum levels in July. After this, levels decreased somewhat sharply and then tended to stabilize or decrease slowly.

Absolute amounts of Mg (Fig. 22) increased in the spring and, after a detectable decrease during bloom and fruit set, reached a maximum in July and then decreased slowly or remained constant, depending on the cultivar.

Cameron and coworkers (26) and Reuther and Smith (125, 126) have previously reported changes in Mg content of the leaves of 'Valencia' orange and 'Washington' navel orange. These are the first reports for the other cultivars. These data are the first to show a decrease in leaf Mg at the time of bloom and fruit set.

## Differences in Average Mineral Element Content of Leaves During the Growing Season

Comparisons between the mineral element content of NFL and FL of the 6 cultivars are shown in Figs. 23 through 27. A summary of the mean values for each element in FL and NFL and the differences between the means are shown in Table 8. Although there were significant differences shown for a number of elements as described in the following section, it should be emphasized that little importance can be given to these differences because of differential fertilization practices and lack of replication.

### Nitrogen

N content of both NFL and FL of 'Murcott' was significantly higher than the N content of the leaves of the other cultivars (Table 8). There were no differences in N content of NFL of the 'Temple' orange, 'Marsh' grapefruit, 'Hamlin' orange, 'Pineapple' orange and 'Valencia' orange. There were significant differences in N content of FL. 'Murcott' was significantly higher in N content than all other cultivars. FL of 'Temple' orange and 'Pineapple' orange contained significantly higher amounts of N than FL of 'Hamlin' orange and 'Marsh' grapefruit.

### Phosphorus

P content of NFL and FL of 'Temple' orange, 'Hamlin' orange, and 'Pineapple' orange was higher than P content of 'Marsh' grapefruit. There were no significant differences between P content of 'Temple', 'Hamlin', 'Pineapple' and 'Valencia' nor between 'Murcott and 'Marsh' in NFL. In FL, 'Temple', 'Hamlin' and 'Pineapple' had the same P content while 'Marsh' leaves contained significantly lower amounts of P.

Table 8. Differences in average mineral element content (% DW) of 4 to 7-month-old leaves from non-fruiting (NFL) and fruiting stems (FL) and fruit (FRT) of 6 citrus cultivars.

| | N | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cultivar | NFL | FL | FRT | NFL | FL | FRT | NFL | FL | FRT |
| Murcott | 3.13a[z] | 3.02a | 1.39a | 0.145b | 0.130ab | .138c | 1.73b | 1.52a | 1.99a |
| Temple | 2.46b | 2.27b | 1.15b | 0.187a | 0.176a | .178a | 1.60b | 1.22ab | 1.21bc |
| Marsh | 2.38b | 1.93d | .94c | 0.135b | 0.102b | .083d | 1.40b | 1.08b | .79c |
| Hamlin | 2.38b | 1.97d | .95c | 0.169a | 0.163a | .159b | 1.51b | 1.49a | 1.37b |
| Pineapple | 2.33b | 2.17bc | 1.01bc | 0.170a | 0.158a | .156b | 2.35a | 1.59a | 1.37b |
| Valencia | 2.38b | 2.02cd | .89c | 0.174a | 0.148ab | .137c | 1.91ab | 1.47a | 1.22bc |

| | Ca | | | Mg | | |
|---|---|---|---|---|---|---|
| Cultivar | NFL | FL | FRT | NFL | FL | FRT |
| Murcott | 2.14d | 2.15c | .29d | 0.389ab | 0.332c | .131c |
| Temple | 4.53a | 4.52a | .44a | 0.414a | 0.388b | .158b |
| Marsh | 3.73bc | 3.99b | .38ab | 0.190c | 0.196d | 0.86e |
| Hamlin | 3.38c | 3.70b | .34c | 0.357b | 0.440ab | .146bc |
| Pineapple | 3.52c | 3.72b | .37ab | 0.360b | 0.429ab | .180a |
| Valencia | 3.53c | 4.19b | .36bc | 0.361b | 0.471a | .110d |

[z] Mean separation, within a given column, by Duncan's multiple range test at 1% level of significance.

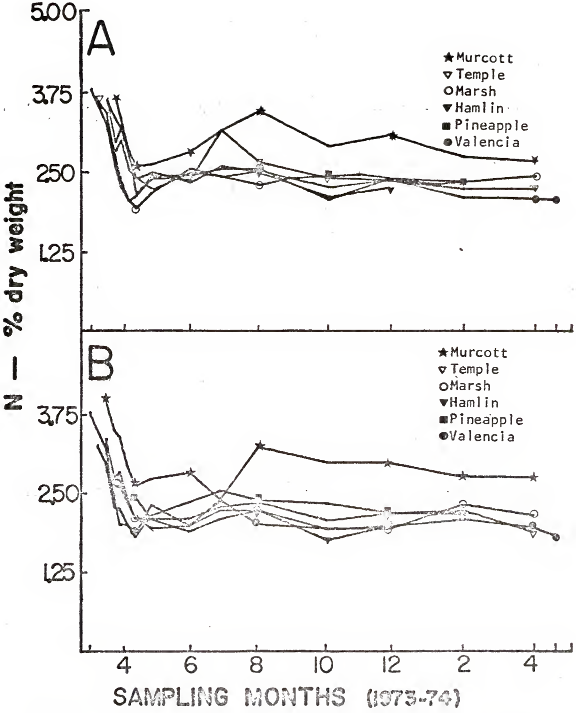

Fig. 23A. N content (% dry weight) of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

Fig. 23B. N content (% dry weight) of leaves from fruiting stems (FL) of 6 citrus cultivars.

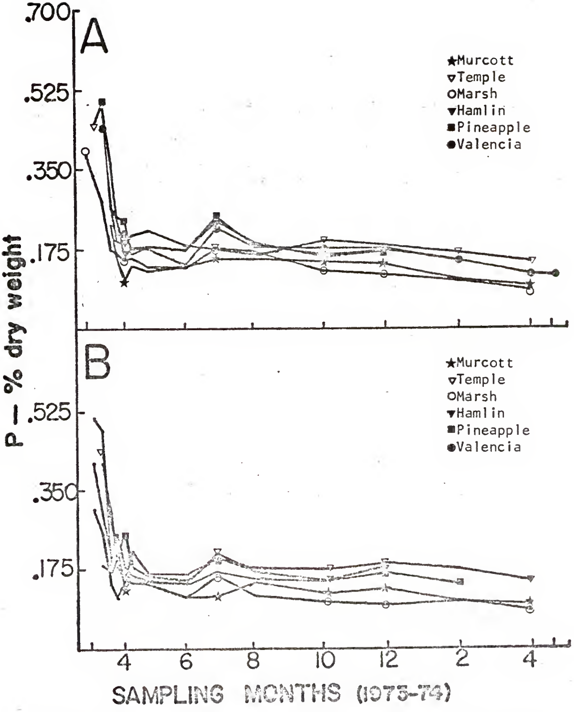

Fig. 24A. P content (% dry weight) of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

Fig. 24B. P content (% dry weight) of leaves from fruiting stems (FL) of 6 citrus cultivars.

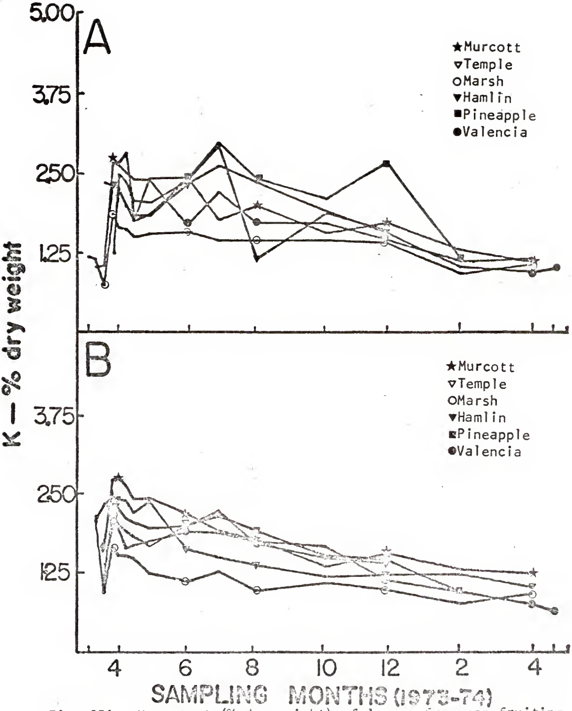

Fig. 25A. K content (% dry weight) of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

Fig. 25B. K content (% dry weight) of leaves from fruiting stems (FL) of 6 citrus cultivars.

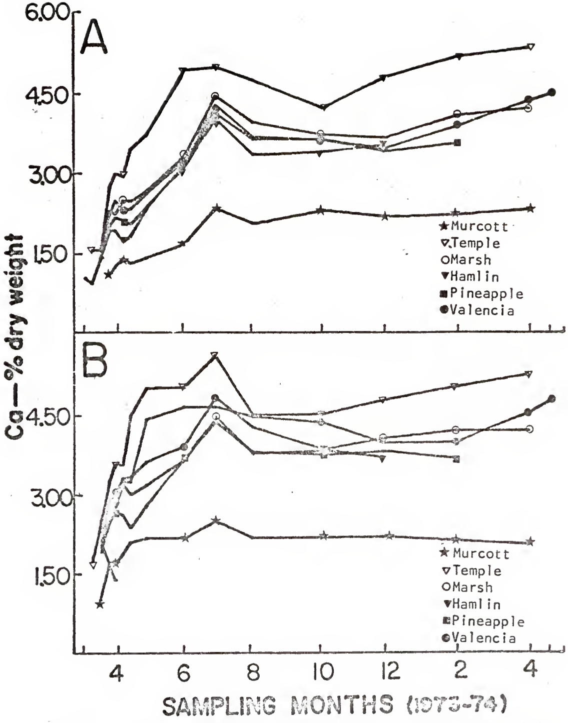

Fig. 26A. Ca content (% dry weight) of leaves from non-fruiting (NFL) of 6 citrus cultivars.

Fig. 26B. Ca content (% dry weight) of leaves from fruiting stems (FL) of 6 citrus cultivars.

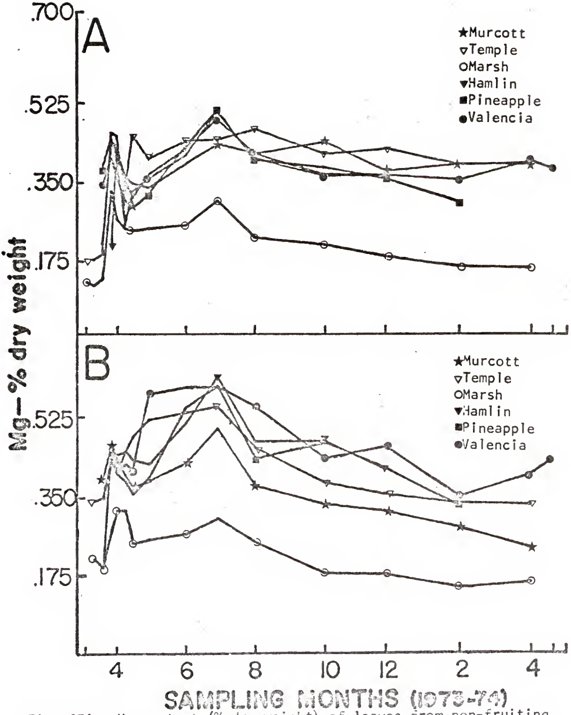

Fig. 27A. Mg content (% dry weight) of leaves from non-fruiting stems (NFL) of 6 citrus cultivars.

Fig. 27B. Mg content (% dry weight) of leaves from fruiting stems (FL) of 6 citrus cultivars.

## Potassium

K was highest in 'Pineapple' orange in both NFL and FL. In NFL there was no difference between 'Pineapple' and 'Valencia' orange, but there were significant differences between 'Pineapple' and the remainder of the cultivars. In FL there were no significant differences between 'Pineapple', 'Murcott', 'Hamlin', 'Valencia' and 'Temple' but K content of 'Marsh' was significantly lower.

## Calcium

Ca was significantly highest in leaves of 'Temple' and lowest in leaves of 'Murcott' for both NFL and FL. In FL the highest Ca content was found in 'Temple' and the lowest Ca was found in leaves of 'Murcott'. There were no significant differences between 'Marsh' grapefruit, 'Pineapple', 'Valencia' and 'Hamlin'. This order does not hold true for NFL. There were significant differences between 'Valencia' and 'Pineapple' and 'Hamlin' but there were no significant differences between 'Valencia' and 'Marsh' grapefruit and between 'Marsh' grapefruit and 'Pineapple' and 'Hamlin'.

## Magnesium

Mg content of NFL was highest in 'Temple' and lowest in 'Marsh' grapefruit. In FL, highest Mg content was found in 'Valencia' and the lowest content was found in 'Marsh' leaves.

## Effect of Fruiting on the Mineral Nutrient Content of Leaves

Mean %DW of the mineral elements in NFL and FL of the 6 cultivars is shown in Table 8. Table 9 summarizes the statistical analysis of the %DW data for the NFL and FL in each of the 6 cultivars using means for both 4- to 7-month old leaves and means for the entire sampling period.

## Difference in mineral element content of leaves from fruiting stems and non-fruiting stems

Significant differences in mineral element contents of the leaves were found (Table 9). In some cases, the amount of an element was higher in NFL than in FL. In others the relative amounts were reversed. Strong mobilization of some elements from the FL to the fruit was shown by the lower quantity of these elements in FL. N, P, and K were generally lower in FL (2, 52, 61, 74, 108) than in the NFL. Ca and Mg (52, 61, 74, 150) were generally higher in the FL than NFL or in equal amounts in both types of leaves.

Previous research has shown that FL can differ in mineral content from NFL of the same age leaves in 'Valencia' orange, 'Washington' navel orange and 'Clementine' mandarin (2, 16, 17, 34, 61, 64, 74, 92, 105, 107, 108, 109, 150). The results of this research agree generally with their results.

The lower values of N, K, and, to a lesser degree, P in FL indicate a definite demand for these elements during fruit development which is satisfied by the absorption of these elements by the roots plus a translocation of them from the FL to the fruit. The higher values of Ca and Mg in the FL of some cultivars could be the result of several factors. Increased absorption of N, particularly in the nitrate form, would enhance the uptake of cations such as Ca and Mg.

## Movement of mineral elements from leaves to fruit

Comparisons of absolute amounts of N, P, K, Ca and Mg in NFL, FL and FRT of the 6 cultivars are shown in Figs. 18 through 22. The effect of translocation of elements from leaves to fruits was apparent from these comparisons. In the spring when growth began, there was a decrease in the absolute amounts of mineral elements in the FL of

Table 9. Statistical comparisons of mean mineral element content of leaves fron non-fruiting (NFL) and fruiting stems FL of 6 citrus cultivars.

a. 4- to 7-month-old leaves.

|  | MURCOTT | TEMPLE | MARSH | HAMLIN | PINEAPPLE | VALENCIA |
|---|---|---|---|---|---|---|
| N | NFL = FL | NFL = FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| P | NFL = FL | NFL = FL | NFL = FL | NFL = FL | NFL > FL | NFL > FL |
| K | NFL > FL | NFL > FL | NFL > FL | NFL = FL | NFL = FL | NFL > FL |
| Ca | NFL = FL | NFL = FL | NFL = FL | NFL = FL | NFL = FL | NFL < FL |
| Mg | NFL = FL | NFL = FL | NFL = FL | NFL < FL | NFL < FL | NFL < FL |

b. leaf samples from entire season.

|  | MURCOTT | TEMPLE | MARSH | HAMLIN | PINEAPPLE | VALENCIA |
|---|---|---|---|---|---|---|
| N | NFL = FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| P | NFL = FL | NFL = FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| K | NFL = FL | NFL = FL | NFL = FL | NFL = FL | NFL = FL | NFL > FL |
| Ca | NFL = FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL |
| Mg | NFL = FL | NFL = FL | NFL = FL | NFL < FL | NFL < FL | NFL < FL |

most cultivars. This effect was most clearly seen in the sweet orange cultivars (Figs. 18 through 22) in which there was a decrease in all elements in the FL at the time young fruit growth began. This decrease was the cause for the significant differences between the amounts of these elements in NFL and FL in later months. In 'Hamlin' there were decreases in NFL for all elements and in 'Pineapple' and 'Valencia' there were decreases in N and P. In 'Temple' and 'Murcott' these decreases in amounts of N, K, Ca, and Mg in FL were also seen, but there was no decrease in the amounts of P in the FL nor for any element in the NFL. In 'Marsh' there were decreases in all elements in the FL and also there was a decrease in K and P in the NFL.

For 'Temple' and 'Murcott', the lack of a decrease in absolute amount of P of FL, while all other cultivars showed a decrease, is probably due to differences in leaf size. 'Temple' and 'Murcott' leaves are smaller than leaves of the other cultivars. The absolute amounts of P per leaf are also very small. A difference in P between NFL and FL may have existed but was too small to be detected. The decrease in K and P of NFL of 'Marsh' grapefruit is probably due to the size of FL of the cultivar. FL of 'Marsh' are very small in comparison to NFL and the FL may, therefore, be unable to provide sufficient quantities of these elements to the fruit.

### Effect of fruiting on sample collection for leaf mineral analysis

From Table 9, a general conclusion about the effect of fruiting on the mineral nutrient levels in the FL can be reached. The amounts of N, P, and K in 4- to 7-month-old FL of 'Valencia' were lower than the amounts in NFL. Amounts of Ca and Mg were higher in FL. For 'Marsh' grapefruit and 'Hamlin' orange, significantly lower amounts of N and P were found in FL. There was no difference between amounts of Ca and Mg in NFL and FL of 'Marsh'. In 'Hamlin' there was a significantly lower level of Mg in the NFL and no difference between Ca content of NFL and FL. Amounts of N, K and Ca were the same in NFL and FL of 'Pineapple'. There was less P in the FL than the NFL of this cultivar while the FL contained larger quantities of Mg than NFL. In 'Murcott' and 'Temple' there were no differences in the amounts of N, P, Ca and Mg in NFL and Fl. K was lower in the FL of these 2 cultivars.

All previous work on mineral element content of citrus leaves has been performed with 'Valencia' orange and 'Washington' navel orange. This work has led to the conclusion that only NFL should be collected for mineral element analysis due to the differences in mineral element content between NFL and FL. The research reported here, however, indicates that the situation for other citrus cultivars may not be the same as previously shown. Additional work should be undertaken to clarify this.

## Effect of Nitrogen and Potassium Fertilization on Mineral Element Content of Leaves and Fruit

### Effect of Nitrogen and Potassium Fertilization on Accumulation of Mineral Elements in Leaves and Fruit

Figs. 28 through 37 show data for the entire sampling period of the mineral element content in the leaves and fruit of 'Valencia' orange on rough lemon rootstock under 4 different levels of N and K fertilization in 6 combinations. Statistical analysis for the 4- to 7-month-old leaves and fruit are summarized in Table 10.

#### Nitrogen

N was highest at level N4K4 and lowest at level N1K4 for both

NFL and FL. There was a decreasing order in amounts of N in both NFL and FL as follows: N4K4, N3K3, N4K1, N2K2, N1K1 and N1K4. However, the differences between certain levels were not statistically significant (Table 10). There were no significant differences between N4K4, N3K3 and N4K1 in both NFL and FL. In NFL, N2K2 was not significantly different from N4K1 and N3K3, but in FL there was a significant difference between N3K3 and N2K2. Further, there were no significant differences between N1K1 and N1K4 in NFL but N1K1 and N1K4 were significantly different in FL.

In FRT, the order of decreasing amounts of N were found in N4K1, N3K3, N4K4, N2K2, N1K1 and N1K4. There were no significant differences between N4K1, N3K3 and N4K4, between N4K4, N2K2 and N1K1 nor between N1K1 and N1K4 (Table 10).

At the lower N levels, in all cases (NFL, FL, and FRT) the order was N1K1 and N1K4. It has been reported that uptake of cations from the soil solution and N in the tissues of citrus plants (148, 151, 162) is directly related to the amount of these materials in the soil solution. These results agree with the previously reported results.

At low levels of N, K depresses the absorption of N. In all 3 types of tissue N amounts were lower in N1K4 than in N1K1. This effect has not been shown previously. At high levels of N, K does not depress the N content in the leaves. K has been shown to have no effect or to promote N uptake. This is shown here and also by other workers (21).

### Phosphorus

P was highest in N1K4 and lowest in N4K1 in NFL. In decreasing order, the levels were N1K4, N3K3, N1K1, N2K2 and N4K1. N1K4 was

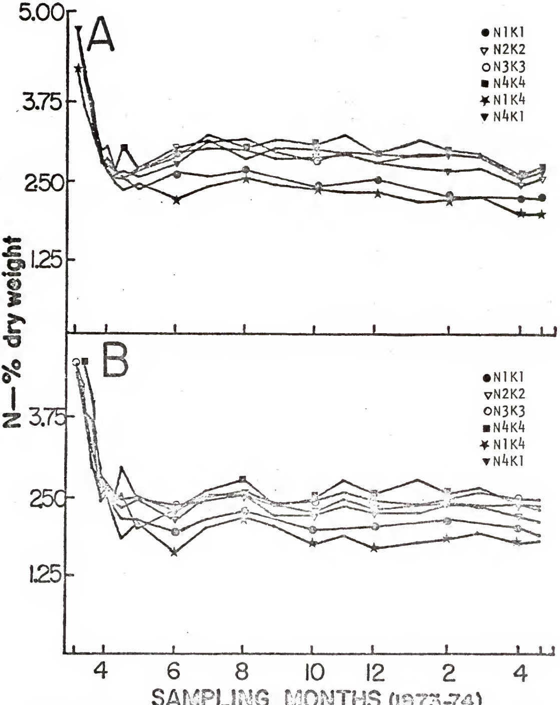

Fig. 28A. N content of leaves from non-fruiting stems (NFL) at varying levels of N and K fertilization.

Fig. 28B. N content of leaves from fruiting stems (FL) at varying levels of N and K fertilization.

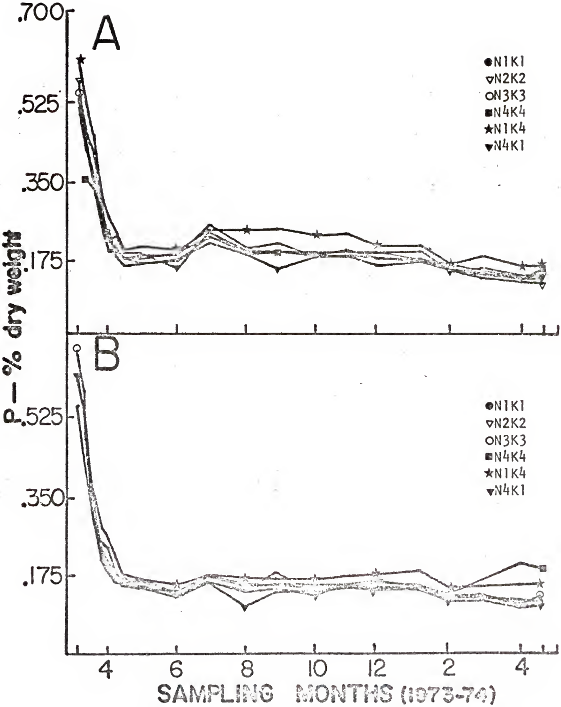

Fig. 29A. P content of leaves from non-fruiting stems (NFL) at varying levels of N and K fertilization.

Fig. 29B. P content of leaves from fruiting stems (FL) at varying levels of N and K fertilization.

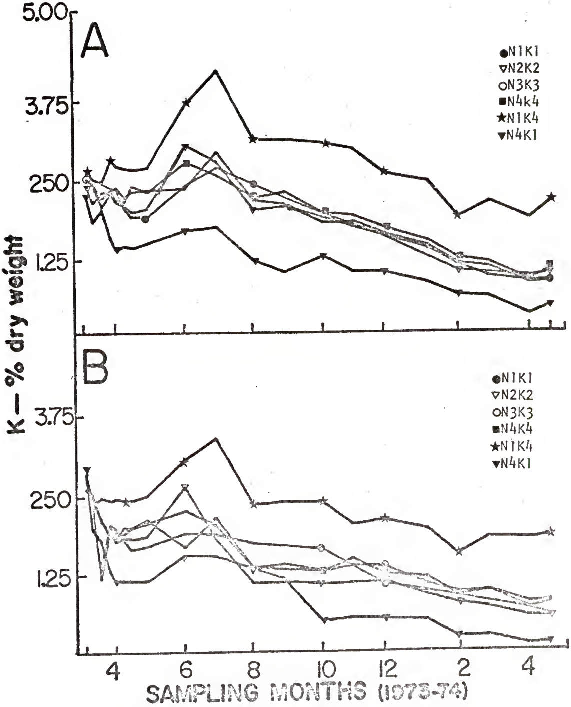

Fig. 30A. K content of leaves from non-fruiting stems (NFL) at varying levels of N and K fertilization.

Fig. 30B. K content of leaves from fruiting stems (FL) at varying levels of N and K fertilization.

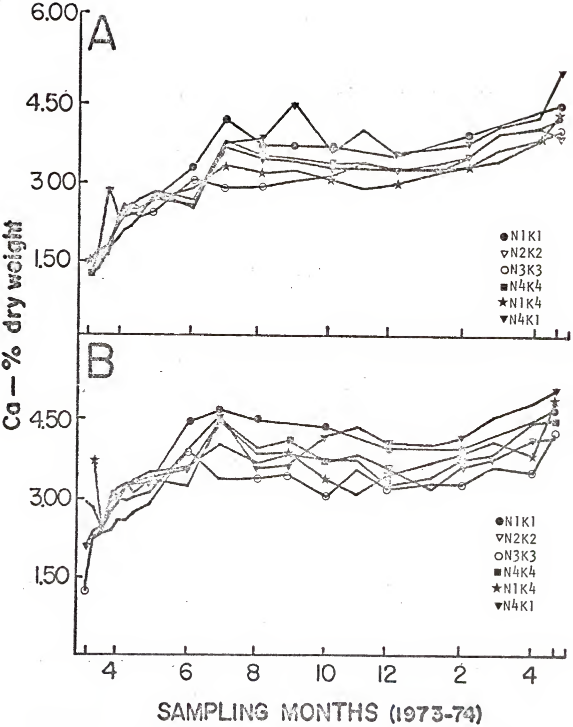

Fig. 31A. Ca content of leaves from non-fruiting stems (NFL) at varying levels of N and K fertilizatio .

Fig. 31B. Ca content of leaves from fruiting st (FL) at varying levels of N and K fertilizati

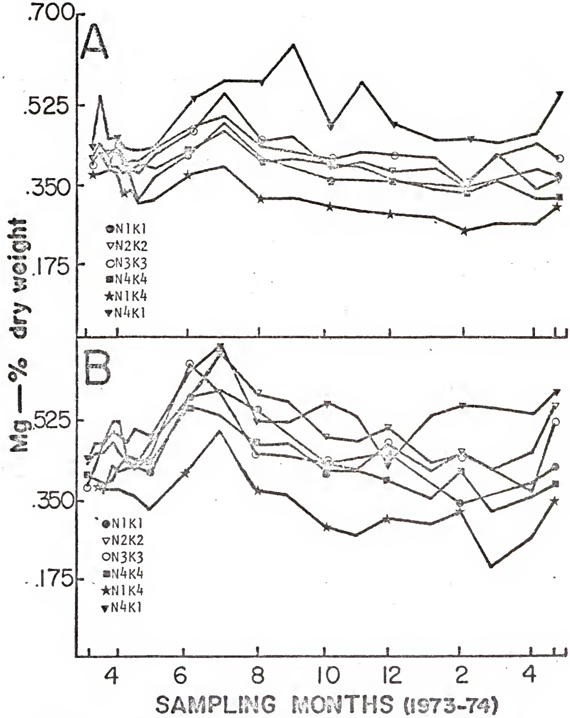

Fig. 32A. Mg content of leaves from non-fruiting stems (NFL) at varying levels of N and K fertilization.

Fig. 32B. Mg content of leaves from fruiting stems (FL) at varying levels of N and K fertilization.

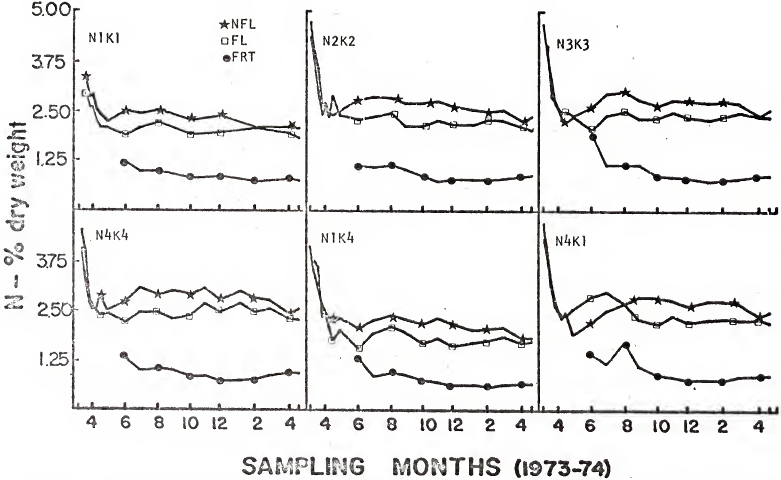

Fig. 33. N content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization.

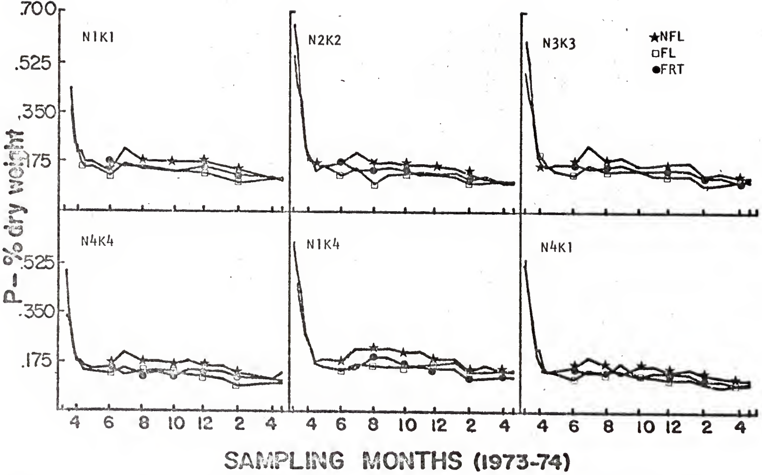

Fig. 34. P content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization.

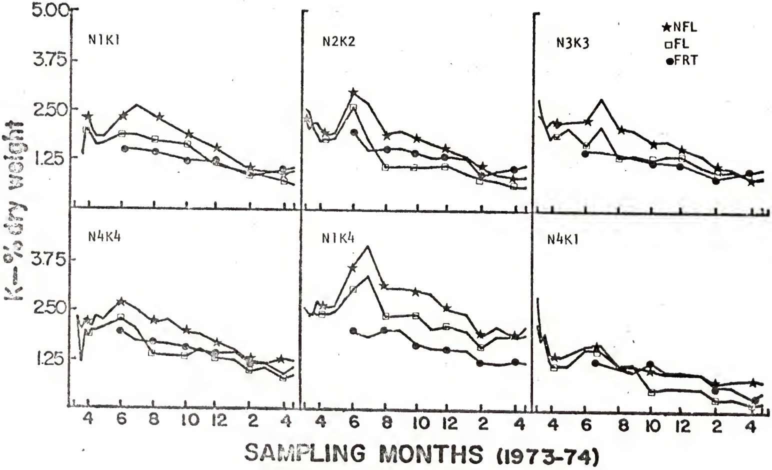

Fig. 35. K content (% dry weight) of leaves from non-fruiting stems (NFL) leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization.

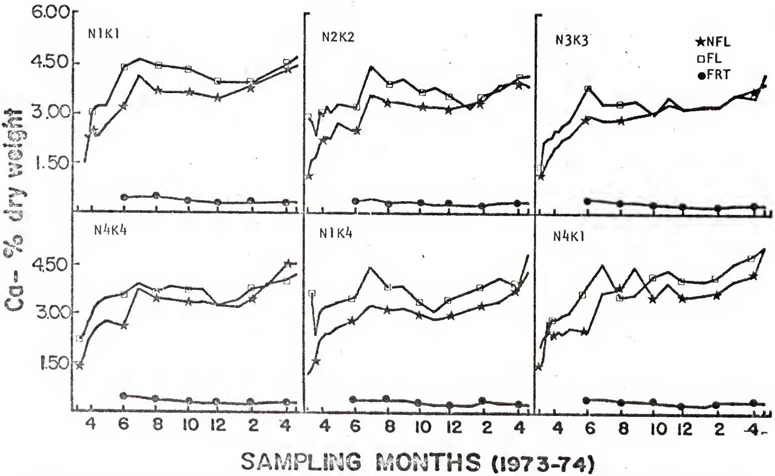

Fig. 36. Ca content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization.

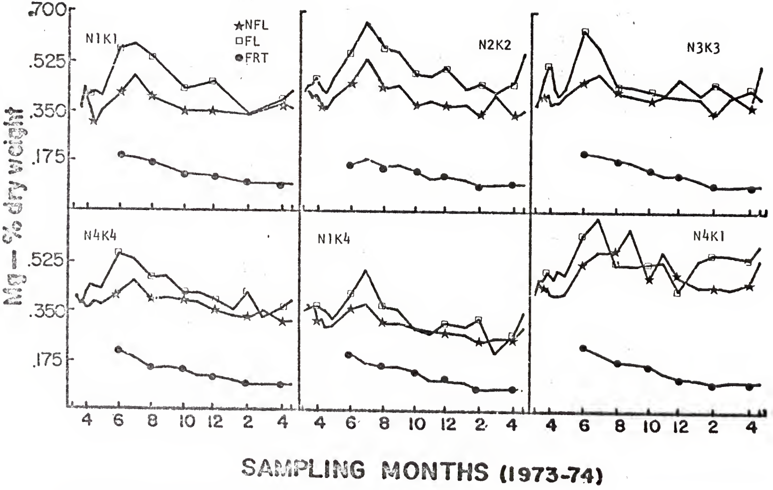

Fig. 37. Mg content (% dry weight) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization.

Table 10. Differences in average mineral element content (% DW) of 4 to 7-month-old leaves from non-fruiting (NFL) and fruiting (FL) and fruit (FRT) stems at varying rates of N and K fertilization.

| Treatments | N | | | P | | | K | | |
|---|---|---|---|---|---|---|---|---|---|
| | NFL | FL | FRT | NFL | FL | FRT | NFL | FL | FRT |
| N1K1 | 2.38c[z] | 2.02c | 0.86bc | 0.174b | 0.148ab | 0.135b | 1.91b | 1.47b | 1.20d |
| N2K2 | 2.72b | 2.26ab | 0.91b | 0.167bc | 0.129c | 0.132b | 1.79b | 1.11c | 1.34c |
| N3K3 | 2.80b | 2.40b | 1.02a | 0.176b | 0.147b | 0.134b | 1.83b | 1.35bc | 1.43b |
| N4K4 | 2.92a | 2.45a | 0.92ab | 0.172b | 0.137bc | 0.122c | 1.94b | 1.33bc | 1.43b |
| N1K4 | 2.26d | 1.84d | 0.78c | 0.212a | 0.163a | 0.151a | 2.87a | 2.22a | 1.54a |
| N4K1 | 2.76b | 2.35ab | 1.02a | 0.156c | 0.144b | 0.124c | 1.05c | 0.78d | 0.96e |

| Treatments | Ca | | | Mg | | |
|---|---|---|---|---|---|---|
| | NFL | FL | FRT | NFL | FL | FRT |
| N1K1 | 3.53ab | 4.19a | 0.35a | 0.362c | 0.471ab | 0.128c |
| N2K2 | 3.23bcd | 3.77abc | 0.31b | 0.400bc | 0.517a | 0.128c |
| N3K3 | 3.05cd | 3.27d | 0.29c | 0.405b | 0.437b | 0.151a |
| N4K4 | 3.31bc | 3.59bcd | 0.30bc | 0.376bc | 0.427b | 0.125cd |
| N1K4 | 2.98d | 3.47cd | 0.31bc | 0.290dq | 0.316c | 0.119d |
| N4K1 | 3.80a | 3.90ab | 0.35a | 0.540a | 0.507a | 0.143b |

[z] Mean separation, within a given column, by Duncan's multiple range test at % level of significance.

significantly higher than N3K3. There were no significant differences between N3K3 and N1K1, N4K4 and N2K2 or N1K1, N4K4, N2K2 and N4K1.

For FL, P was highest in N1K4 and lowest in N2K2. The decreasing order was N1K4, N1K1, N3K3, N4K1, N4K4 and N2K2.

In FRT (Table 10) the decreasing order was N1K4, N1K1, N3K3, N2K2, N4K1 and N4K4. There were no significant differences between N1K1, N3K3 and N2K2 and between N4K1 and N4K4. The results in both types of leaves showed an apparent reciprocative effect between P and N, highest P levels at lowest N levels and *vice versa*.

It has been reported (30, 50, 55, 120, 123, 148, 151, 162) that increasing N supply causes decreases in leaf P. Leaf P is often more dependent upon leaf N than upon the supply of available P. P is a weak antagonizer of N but N has a strong effect on P. Leaves in the low or deficient range for N may show P in the high or excess range and leaves excessively high in N may show deficient levels of P (151).

### Potassium

K is highest in N1K4 and lowest in N4K1 for both NFL and FL. In NFL the decreasing order is N1K4, N4K4, N1K1, N3K3, N2K2 and N4K1. There were significant differences between N1K4 and N4K4. There were no significant differences between N4K4, N1K1, N3K3 and N2K2. There were significant differences between N2K2 and N4K1.

In FL the decreasing order of K content was N1K4, N1K1, N3K3, N4K4, N2K2, and N4K1. N1K4 was significantly higher than the other NK combinations but no significant differences were found between N1K1, N3K3, N4K4 or between N3K3, N4K4 and N2K2.

In FRT, K ranged in decreasing order N1K4, N3K3, N4K4, N2K2, N1K1 and N4K1. The differences between NK levels were significant except for the differences between N3K3 and N4K4.

At the lowest and highest levels of applied N, there was a direct relationship between applied K and K content of NFL, FL and FRT. At intermediate levels of K, an antagonistic effect of N on K absorption was seen, as shown by the fact that K in the leaves was higher in N1K1 than in N4K1, N2K2 and N3K3. Effects similar to the results of this research have been previously reported (30, 50, 53, 112, 116, 125, 148, 151, 162). Others have reported that factors which lead to a high level of either N or K tend to lower the level of the other (148, 151, 162). There have been previous reports that N depresses K at low K levels (162) and at intermediate K levels (21). The research reported here shows that N depresses K even at high K levels in NFL, FL and FRT. In spite of these findings, it is possible to have moderately high N and K in the same tissue in plants growing at moderately high N and K levels (150).

The plant species has an effect on the degree of N-K antagonism. It has been shown that the ammonium ion strongly depresses leaf K, Ca and Mg in citrus leaves but had no effect in beans (173).

### Calcium

Ca was highest in N4K1 and lowest in N1K4 for NFL. The decreasing order of Ca content was N4K1, N1K1, N4K4, N2K2, N3K3 and N1K4. There were no significant differences between N4K1 and N1K1, between N4K4, N2K2 and N3K3 or between N1K1, N4K4 and N2K2 or between N2K2, N3K3, and N1K4.

For FL, Ca content was highest in N1K1 and lowest in N3K3 with a decreasing order of N1K1, N4K1, N2K2, N4K4, N1K4 and N3K3. There were no significant differences between N1K1, N4K1 and N3K3 or between N4K1, N2K2 and N4K4 or between N2K2, N4K4 and N1K4.

In FRT a decreasing order of Ca amounts was found in N4K1, N1K1, N2K2, N1K4, N4K4 and N3K3. There were no significant differences between N4K1 and N1K1, between N2K2, N1K4 and N4K4, nor between N1K4, N4K4 and N3K3.

Highest levels of Ca were found at the lowest levels of K and vice versa. This is in agreement with previous research reports where a reciprocative relationship between K and Ca has been shown (50, 112, 116, 148, 151, 162). N fertilization does not affect Ca levels except at high N levels. At high N levels, Ca in the tissues is generally high but at intermediate levels of N and K, little influence on Ca levels has been shown.

Magnesium

Mg was highest in N4K1 and lowest in N1K4 for both NFL and FL. In NFL the order of decreasing Mg content was N4K1, N3K3, N2K2, N4K4, N1K1 and N1K4. There were significant differences between N4K4 and N3K3, between N1K1 and N1K4, but no significant differences between N3K3, N2K2, N4K4 and N1K1.

In FL, the decreasing order of Mg content was N4K1, N2K2, N1K1, N3K3, N4K4 and N1K4. There were significant differences between N4K4 and N1K4 but no significant differences between N4K1, N2K2 and N1K1 or between N1K1, N3K3 and N4K4.

In FRT, Mg was found in decreasing amounts in N3K3, N4K1, N1K1, N2K2, N4K4 and N1K4. There were no significant differences between N3K3 and N4K1 nor between N1K1, N2K2 and N4K4.

The results indicate an antagonistic effect of K on Mg and a synergistic effect of N on Mg. These effects have been previously documented (50, 112, 116, 125, 148, 151, 162). These workers have reported that at high N levels, Mg content of citrus tissues increases especially with non-base sources of N, such as urea, anhydrous ammonia and ammonium sulfate. This effect may be nullified by high rates of K. Although K is a strong antagonist of Mg, Mg is a weak antagonist of K. Under conditions of high Ca substrate, K is somewhat less antagonistic to Mg, apparently due to the unequal 3-way competition between K, Ca and Mg in which Ca antagonizes K more strongly than it does Mg (151, 154, 155, 162). In Florida, low Mg levels in citrus trees are reported to be sometimes due to excessive applications of K. The Mg deficiency symptoms are corrected by reducing applied K rather than increasing Mg (123, 125).

## Effect of Fruiting on the Mineral Element Content of Leaves

Table 10 shows mean mineral element content of NFL, FL and FRT for each fertilization level. Statistical comparisons of this data are shown in Table 11. Figs. 33 through 42 compare %DW and absolute amounts of each element in the NFL, FL and FRT at the 6 levels of NK fertilization.

Statistical analysis of the data shown in Figs. 33 through 42 shows that conclusions based on 4- to 7-month-old leaves are different from conclusions based on means for the entire season (Table 11) Based on 4- to 7-month-old leaves, fruiting decreases the amount of N, P and K in the FL, except for P and K at the N4K1 level of fertilization. Based on seasonal means, fruiting decreases the amount of N and K in the FL but the amount of P is decreased only at the N1K1, N1K4 and N4K1 levels of fertilization. This inconsistency is unexplainable from these data. Comparing seasonal means, Ca and Mg were always lower in NFL than in FL. The same

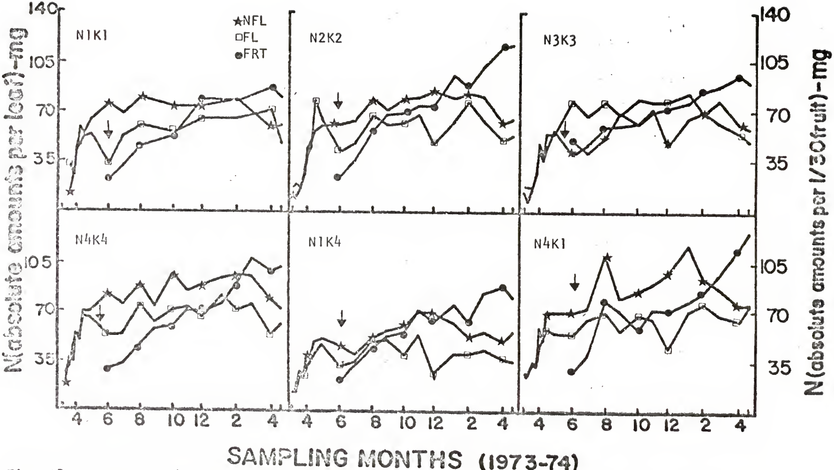

Fig. 38. N content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization. Depression in amounts due to early fruit growth indicated by ↓ .

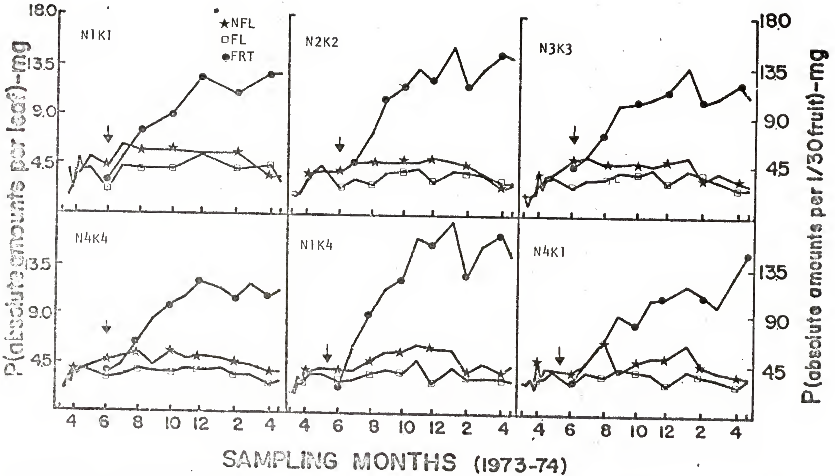

Fig. 39. P content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization. Depression in amounts due to early fruit growth indicated by ↓.

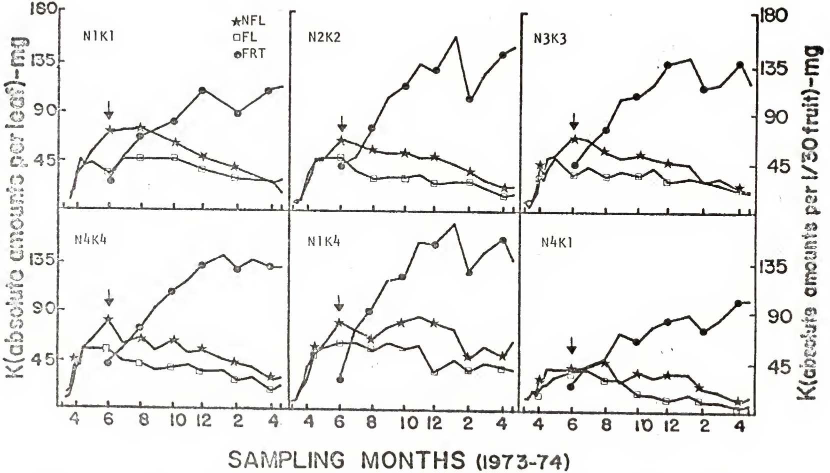

Fig. 40. K content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization. Depression in amounts due to early fruit growth indicated by ↓ .

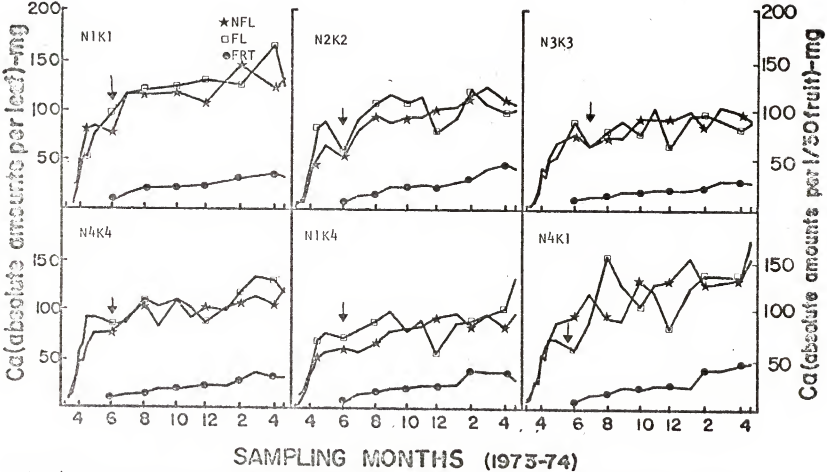

Fig. 41. Ca content (absolute amounts) of leaves from non-fruiting stems (NFL), leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization. Depression in amounts due to early fruit growth indicated by ↓.

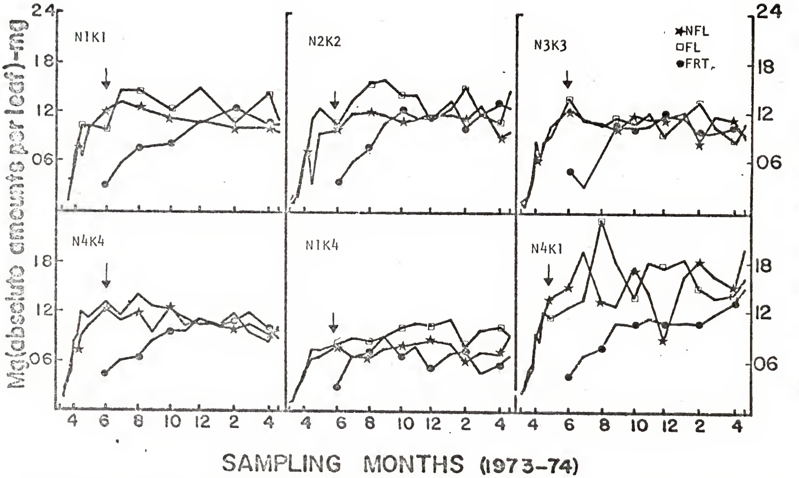

Fig. 42. Mg content (absolute amounts) of leaves from non-fruiting stems (NFL) leaves from fruiting stems (FL) and fruit (FRT) at varying levels of N and K fertilization. Depression in amounts due to early fruit growth indicated by ↓ .

Table 11. Statistical comparisons of mean mineral element content of leaves from non-fruiting (NFL) and fruiting stems (FL) at varying rates of N and K fertilization.

a. 4- to 7-month-old leaves.

| | N1K1 | N2K2 | N3K3 | N4K4 | N1K4 | N4K1 |
|---|---|---|---|---|---|---|
| N | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| P | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL = FL |
| K | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL = FL |
| Ca | NFL < FL | NFL < FL | NFL = FL | NFL < FL | NFL < FL | NFL = FL |
| Mg | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL = FL | NFL = FL |

b. leaf samples from entire season.

| | N1K1 | N2K3 | N3K3 | N4K4 | N1K4 | N4K1 |
|---|---|---|---|---|---|---|
| N | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| P | NFL > FL | NFL = FL | NFL = FL | NFL = FL | NFL > FL | NFL > FL |
| K | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL | NFL > FL |
| Ca | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL |
| Mg | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL | NFL < FL |

relationship was found in 4- to 7-month-old leaves except for Ca in N3K3 and N4K1 and for Mg in N1K4 and N4K1.

N, P, and K are lower in FL than NFL because these elements are easily translocated and retranslocated. Thus, fruit growth removes larger quantities of these elements from the FL than from the NFL. Ca and Mg are higher in FL than NFL due to the antagonistic effect of K on the 2 elements.

Further, the effect of fruiting on amounts of N, P, K, Ca and Mg in the FL varies according to N and K nutritional levels. For N, at lower N fertilization rates, the decrease in amount of N in the FL at the time of fruit set and young fruit growth was greatest and the effect diminished as N rate increased (Fig. 38). For P, there were no differences between P content of FL or NFL due to the effect of fruiting which were affected by the levels of N or K fertilization (Fig. 39). For K, the differences between absolute amounts of K in FL and NFL did not occur until sometime after young fruit growth began (Fig. 40). This would be the expected pattern since fruit demand for K is low early in the growing season and increases rapidly during summer and early fall (134). Further, the decline in K amounts in both NFL and FL was greater at the lower levels of K fertilization and lessened as K fertilization rate was increased.

## Comparisons of Changes in Physical Characteristics to Changes in Mineral Element Content

### Effect of Leaf Mineral Element Content on Leaf Size

The regression of N, P, K, Ca and Mg on AR is shown in Table 12. From Table 12 certain effects of mineral element content on AR of leaves in the sample represents accurately the average size of leaves on the entire tree is very important. This is in partial agreement with other research findings. Some workers (34, 165, 172) have indicated that the effect of size on %DW determinations is inconsequential. Others (165) have indicated that size affects the outcome of determinations for some elements (particularly K) but not for N, P, Ca, Mg, Fe, Zn, Mn and Cu.

The effect of NK levels on N content, AR and size of citrus leaves are reasons for the improvements in tree canopy and yield which are commonly associated with N fertilization (159, 161, 162).

The regression of AR on %DW P indicates that the same precautions in taking leaf samples as described for %DW N determinations are equally as important for %DW P determinations. The data in Table 12 shows that there was no effect of NK level on the regression of AR on %DW P.

The lack of a relationship between %DW K and AR (Table 12) indicates that leaf size does not affect the outcome of leaf mineral element determinations for K. The NK experiment data (Table 4) does not show any effect of K level on size of leaves but does show an effect on FW and DW. High K reduces FW and DW. This finding agrees with previous work of Smith _et_ _al_. (158).

The high positive regression of AR on %DW Ca indicates that increasing Ca levels strongly increase leaf size. Further, differences in leaf size when sampling would have major effects on %DW Ca determinations from leaf mineral analysis.

Mg levels in citrus leaves are apparently not related to leaf area.

Table 12a. Regression of leaf (AR) on %DW N content of leaves from 6 citrus cultivars.

| Cultivars or treatments | Intercept | Slope | Correlation number (r)[z] |
|---|---|---|---|
| Murcott | 17.701 | - 2.366 | -0.552 |
| Temple | 13.063 | - 1.960 | -0.287 |
| Marsh | 43.003 | - 7.593 | -0.585* |
| Hamlin | 52.402 | -11.717 | -0.839** |
| Pineapple | 57.290 | -12.643 | -0.845** |
| Valencia | 48.529 | -11.428 | -0.768** |
| N1K1 | 48.529 | -11.428 | -0.768** |
| N2K2 | 48.853 | -10.360 | -0.694** |
| N3K3 | 39.911 | - 6.432 | -0.358 |
| N4K4 | 39.170 | - 6.079 | -0.382 |
| N1K4 | 43.449 | -10.309 | -0.742** |
| N4K1 | 47.051 | - 8.777 | -0.464 |

[z] Significant at 5% (*), 1% (**).

Table 12b. Regression of leaf (AR) on %DW P content of leaves from 6 citrus cultivars.

| Cultivars or treatments | Intercept | Slope | Correlation number (r)[z] |
|---|---|---|---|
| Murcott | 14.415 | -26.986 | -0.627* |
| Temple | 12.937 | -22.467 | -0.737** |
| Marsh | 35.698 | -72.448 | -0.834** |
| Hamlin | 34.475 | -59.255 | -0.925** |
| Pineapple | 38.768 | -65.537 | -0.934** |
| Valencia | 31.157 | -55.852 | -0.830** |
| N1K1 | 31.157 | -55.852 | -0.830** |
| N2K2 | 31.280 | -58.129 | -0.859* |
| N3K3 | 26.161 | -36.637 | -0.457 |
| N4K4 | 31.348 | -53.370 | -0.627 |
| N1K4 | 31.099 | -51.407 | -0.798** |
| N4K1 | 30.128 | -40.228 | -0.457 |

[z] Significant at 5% (*), 1% (**).

Table 12c. Regression of leaf (AR) on %DW K content of leaves from 6 citrus cultivars.

| Cultivars or treatments | Intercept | Slope | Correlation number (r)$^z$ |
|---|---|---|---|
| Murcott | 11.727 | -0.528 | -0.205 |
| Temple | 11.304 | -1.677 | -0.365 |
| Marsh | 18.504 | 4.674 | 0.358 |
| Hamlin | 17.791 | 1.854 | 0.155 |
| Pineapple | 16.859 | 3.409 | 0.261 |
| Valencia | 23.487 | -1.613 | -0.171 |
| N1K1 | 23.487 | -1.613 | -0.171 |
| N2K2 | 26.075 | -2.777 | -0.394 |
| N3K3 | 17.151 | 1.335 | 0.189 |
| N4K4 | 23.554 | -0.725 | -0.104 |
| N1K4 | 22.478 | -0.826 | -0.115 |
| N4K1 | 28.112 | -4.207 | -0.431 |

$^z$ Significant at 5% (*), 1% (**).

Table 12d. Regression of leaf (AR) on %DW Ca content of leaves from 6 citrus cultivars.

| Cultivars or treatments | Intercept | Slope | Correlation number (r)$^z$ |
|---|---|---|---|
| Murcott | 8.49 | 1.241 | 0.397 |
| Temple | 0.127 | 2.116 | 0.908** |
| Marsh | 16.976 | 2.556 | 0.591* |
| Hamlin | 10.135 | 4.278 | 0.557 |
| Pineapple | 12.516 | 4.214 | 0.576* |
| Valencia | 8.496 | 3.853 | 0.666** |
| N1K1 | 8.496 | 3.853 | 0.666** |
| N2K2 | 10.920 | 3.447 | 0.570** |
| N3K3 | 14.717 | 1.719 | 0.289 |
| N4K4 | 15.580 | 2.169 | 0.410 |
| N1K4 | 8.614 | 4.054 | 0.609** |
| N4K1 | 17.321 | 1.823 | 0.028 |

$^z$ Significant at 5% (*), 1% (**).

Table 12e. Regression of leaf (AR) on %DW Mg content of leaves from 6 citrus cultivars.

| Cultivars or treatments | Intercept | Slope | Correlation number (r)$^z$ |
|---|---|---|---|
| Murcott | 15.434 | -12.652 | -0.303 |
| Temple | 2.502 | 14.451 | 0.376 |
| Marsh | 23.952 | 4.53 | 0.0641 |
| Hamlin | 10.491 | 31.389 | 0.400 |
| Pineapple | 26.695 | - 6.480 | -0.059 |
| Valencia | 17.741 | 7.480 | 0.062 |
| N1K1 | 17.741 | 7.480 | 0.062 |
| N2K2 | 28.198 | -17.812 | -0.206 |
| N3K3 | 8.065 | 28.293 | 0.215 |
| N4K4 | 22.990 | - 2.117 | -0.020 |
| N1K4 | 40.933 | - 6.833 | -0.654 |
| N4K1 | 19.685 | 7.858 | 0.353 |

$^z$ Significant at 5% (*), 1% (**).

# SUMMARY AND CONCLUSIONS

1. NFL and FL of all cultivars grew in an asymmetrical sigmoid pattern reaching maximal FW, DW, WD, LH and AR within the first 4 to 5 weeks of growth.
2. Fruiting reduced leaf size on 'Marsh', 'Hamlin' and 'Pineapple' but not on 'Temple', 'Murcott' and 'Valencia'. These differences were established during the time of leaf expansion.
3. AR of leaves was highly correlated with other leaf parameters indicating that measurement of only 1 leaf parameter might be used to estimate leaf area.
4. High N fertilization rates resulted in leaves of larger size and of greater DW and density.
5. High K fertilization rates have no effect on final leaf size, but do increase the fresh weight of leaves when compared to low K rates.
6. The cultivars in this study showed 2 definite patterns of fruit growth and maturation. 'Hamlin' and 'Marsh' reached maturity very soon after completion of State II of fruit growth. 'Pineapple', 'Temple', 'Valencia' and 'Murcott' exhibited a long period of maturation in Stage III of fruit growth.
7. Differences in fruit growth patterns of the cultivars were observed. Density of 'Marsh' increased throughout growth while density was constant for the other cultivars. Diameter/length ratio was constant for the sweet oranges while it increased for 'Marsh', 'Murcott' and 'Temple' indicating that the flattened shape of

these cultivars was the result of more rapid growth in diameter than length throughout fruit expansion.

8. NK treatments influenced fruit size of 'Valencia' orange, low K and high N resulting in small fruit and high K and low N resulting on larger fruit.
9. The pattern of seasonal changes in N, P, K, Ca and Mg in the fruit and leaves of all 6 cultivars was the same and these changes followed the same pattern as previously reported for all 5 elements in the leaves of 'Valencia' and 'Washington' navel orange and for N in the fruits of 'Valencia' and Washington Navel oranges, 'Marsh' grapefruit and 'Eureka' lemon.
10. Early fruit growth caused a decrease in absolute amounts of N, P, K, Ca and Mg of leaves on fruiting stems of all cultivars and a decrease in the leaves from non-fruiting stems of some but not all cultivars.
11. The decrease in mineral element of leaves was not easily discernible from % DW data but was clearly seen in absolute amount data, indicating that absolute amount data is more useful for observing small changes in mineral element content.
12. Fruiting reduced the content of N, P and K and increased the content of Ca and Mg in the leaves from fruiting stems throughout the growing season.
13. Increasing N levels in the soil increased the amount of N in the leaves and fruit. Lower N content in leaves was found in low N and K, but not at high N and K levels.
14. P content of leaves and fruit was strongly influenced by N levels. Low P was associated with high N fertilization.

15. K fertilization had a direct effect on K content of the leaves and fruit at either high or low levels of N fertilization. At intermediate levels of K, an antagonistic effect of N on K was observed.

16. Ca levels in leaves and fruit were depressed by increasing levels of K fertilization. N fertilization had a synergistic effect on Ca levels in leaves but only at high N and low K fertilization levels.

17. There was a strong antagonistic effect of K fertilization levels on Mg content of the leaves and fruit and a strong synergistic effect of N fertilization levels on Mg content of leaves and fruit.

18. Differences between amounts of N, P, K, Ca and Mg in the NFL and FL were influenced by the level of N and K fertilization.

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# BIOGRAPHICAL SKETCH

Le Nguyen Khoi was born on March 29, 1938, at Hue, Vietnam. He attended elementary school in Bien hoa and secondary school in Saigon, Vietnam, graduating from high school in June 1960. He received the degree of 'Ky-su nong khoa,' which is equivalent to Bachelor of Science in Agriculture from Vietnam National Agricultural College in December 1964. From February 1965 to July 1970 he served as laboratory and field instructor at the same college where he graduated. During that time, from June 1967 to June 1968 he was named Director of Extension Service of the Ministry of Agriculture, and completed the Rice Production Course at the International Rice Institute in Hawaii and in the Philippines. In September, 1970, he entered the Graduate School of the University of Florida under the contract between the U.S. Government and the Government of the Republic of Vietnam. From June 1975, he was employed as a graduate assistant in the Department of Fruit Crops until he received the degree of Doctor of Philosophy in March, 1976.

Le Nguyen Khoi is married to the former Le-thi Anh Nguyet and has three sons, Le Nguyen Khoa (11), Le Nguyen Giap (10) and Le Nguyen Vy (8). In 1974, he remarried to the former Ampai Ampaipetakwong and has one daughter, Le Nguyen Binh Minh (1).

He is a member of the Florida State Horticultural Society, the American Society for Horticultural Science, Gamma Sigma Delta, and is the founder and chief instructor of the University of Florida Aikido Club.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

WJWiltbank

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Associate Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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